

# **LABORATORY INVESTIGATION OF DRY LEAN CONCRETE WITH COPPER SLAG**

**A Dissertation Submitted**

**in partial fulfillment of the requirements for  
award the of degree of**

**MASTERS OF ENGINEERING  
IN  
STRUCTURAL ENGINEERING**

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**July 2016**

## DECLARATION

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I, Varinder Kumar, hereby declare that this thesis report entitled “**Laboratory Investigation of Dry Lean Concrete with Copper Slag**” submitted in the partial fulfillment of the requirements for the award of degree of Master of Engineering in Structural Engineering, in the Civil Engineering Department, Thapar University, Patiala, is work done by me.

This matter embodied in this report has not been submitted in part or full to any other university or institute for the award of any degree.

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## CERTIFICATE


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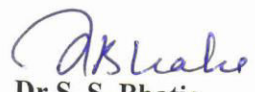
This is to certify that above statement made by the student concerned is correct and true to the best of my knowledge and belief.

  
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## ACKNOWLEDGEMENT

With my aesthetic attitude of learning management to the best, I am in a state to submit this precipitous report and would like to express my gratitude to all persons and organizations who contributed directly or indirectly to this report with their support, encouragement and advice.

Acknowledgement is due first and foremost to my supervisors, Dr. Maneek Kumar , Professor and Mr. Tanuj Chopra ,Assistant Professor Department of Civil Engineering. I am truly indebted for their advice and guidance. Their abundant knowledge in civil and construction field is a benefit for me.

The preparation of this project report would not have been possible without the support and invaluable inputs from key individuals. This report required hard work, sincerity and devotion which I tried my best to put in this project and in turn gained a lot of knowledge and confidence from this report, I would like to extend my gratitude to all my colleagues who have provided assistance in various occasions, especially *Ram Sumiran*. I truly value their assistance and valuable views. Last but not least, my gratitude and thank goes to my family members for their support and motivation. I render my gratitude to Almighty who bestowed self confidence, ability and strength in me to complete this work.

I would like to end by saying that the people mentioned above will hold dear in my heart and will never be forgotten. Thank you all.

(Varinder Kumar)

821122016

## ABSTRACT

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At present about 33 million tonnes of copper slag is generated annually worldwide, India contributing 6 to 6.5 million tones of this slag. As per scientific estimate, for every tonne of copper metal produced, around 1.8-2.2 tonnes of slag is generated. In states like Kerala, Maharashtra and Gujarat, sand mining in rivers has already been banned owing to its disastrous impact ecology. “Therefore, slag has a big potential of getting developed as a suitable alternative material to these resources”. With increasing shortage of river sand and natural aggregates across the country, construction sector is under tremendous pressure to explore alternative to these basic construction material to meeting growing demand of infrastructure demands.

The reuse of waste materials derived from industry waste is growing all over the world. One of the most environmentally responsible ways of meeting the challenges of sustainability in construction is the use of slag in new construction. The main objective of the study is to investigate the effect of using copper slag in lieu of natural fine aggregate on strength properties of Dry lean Concrete.

Dry Lean Concrete (DLC) is an important part of modern rigid pavement. It is a plain concrete with a large ratio of aggregate to cement than conventional concrete and generally used as a base/sub-base of rigid pavement. The compaction of DLC is done under 10 to 12T vibratory roller in field , that’s why it is also known as **Roller – Compacted Concrete** or RCC concrete.

From all the combination it is observed that Density is maximum(2.571 g/cc) of the mix (S-CS-20-80) where 20% Fine Aggregate and 80% Copper Slag at 5.0% moisture content from this we can say that density of mix increases with the increases of copper slag in the mix and it uses less moisture content. It is due to the density of copper slag is more that the densities of sand and copper slag also having a less water absorption.

From all the combinations of mixes it observed that Compressive Strength of 28days is maximum(22.49 N/mm<sup>2</sup>) of the mix S-CS-60-40 at 5.0% moisture content

From all combination it is concluded that although 28days compressive strength is Maximum in the Mix S-CS-60-40 but compressive strength (28 days) of Mixes S-CS-40-60 & S-CS-20-80 are also very near to the maximum strength 22.35 N/mm<sup>2</sup> and 21.98 N/mm<sup>2</sup> respectively at the same moisture content.

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## **OBJECTIVE**

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In this modern situation carbon production and sand mining are major worry due to its dangerous effect to environment and making serious imbalance to the environment. Various studies have been conducted to reduce harsh effect on surroundings, using by-product like copper-slag as partial replacement of sand. Different researchers have also discovered various uses of copper-slag as a replacing agent in finding the strength of concrete.

The utilization of copper slag as partial replacement of sand in manufacturing of Dry lean Concrete was explored in the present study. Copper slag was used at 20, 40, 60 and 80% replacement levels in dry lean concrete. The effect of copper slag on Density and Compressive strength of dry lean concrete was investigated.

## **1.1 INTRODUCTION TO CONCRETE PAVEMENTS**

A pavement is a multi-layered structure part of the road, and layered are placed one over other. Each layer of the pavement is designed to bear the vehicular load/stress. The top layer of pavement should withstand the abrasive action of wheels of vehicles in addition vehicular stresses/ loads. The layers of pavement can be made up of either materials or unbounded material. In general the pavement should withstand the vehicular loading stresses and deterioration from the effects of weather and the grinding action of wheels of vehicles for a specified designed period. Depending upon the material used and behavior under load, pavements are classified as under:

A) Concrete pavement

Concrete pavements are also called rigid pavements.

B) Bituminous pavement.

Bituminous pavements are called flexible pavements.

C) Block Pavement

This types of pavements is neither rigid, nor flexible.

D) Composite pavement.

This types of pavements is also neither rigid, nor flexible

The main components of a pavement are as under

1. Foundation

The foundation comprises sub grade soil and sub-base. The foundation of pavement provides support for the higher layers. Therefore it should withstand the loads to be transferred from the upper layer.

2. Base course

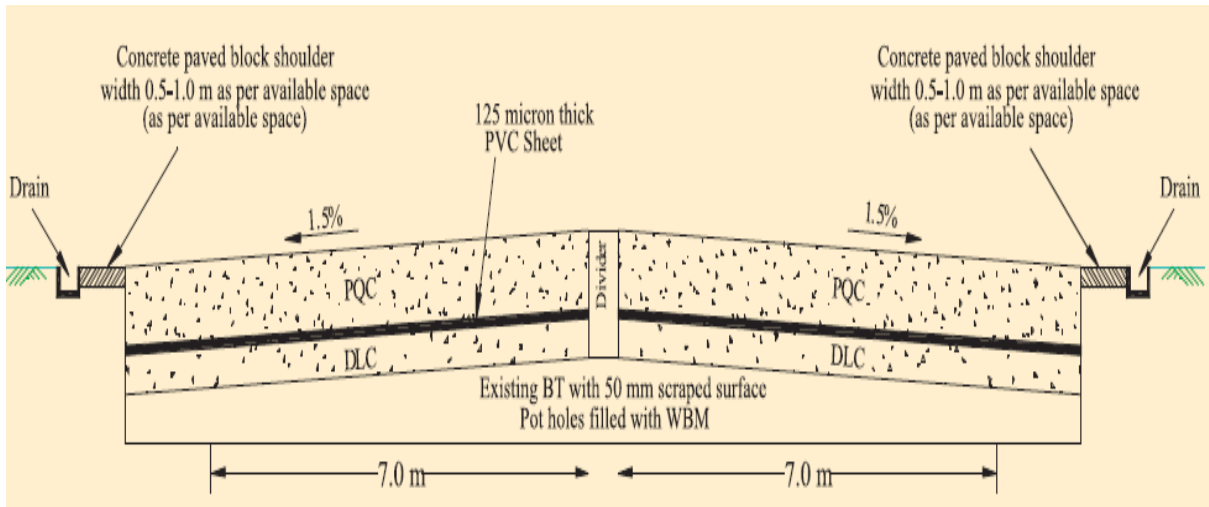
The base course of pavement is its main structural part which bears the vehicular load.

3. Surfacing

It is the topmost layer of pavement and have appropriate resistance to skidding and crack formation.

**Concrete pavement** consists of three layers, i. e. sub-grade, base course and top concrete layer. *Base layers* for concrete pavement are generally made up of bonded materials such as

Dry Lean Concrete, Roller Compacted Concrete. M40 to M50 grade of concrete is generally used in construction of top concrete layer / slab.



**Figure 1.1:** Typical cross-section of the concrete road (central road research institute, 2010)

## 1.2 COMPONENTS OF CONCRETE PAVEMENT

### 1.2.1 Sub-grade

Sub-grade is the natural or filled soil on which the pavement is constructed. The sub-grade supports the load from pavement.

The sub-grade and sub base for lying of paving concrete slabs shall comply with the following requirement: (IRC: 15-1991)

- No soft spots are present in the sub-grade or sub-base.
- The uniformly compacted sub-grade or sub- base extends at least 300 mm on either of width to be concreted.
- It should be properly drained.
- The maximum modulus of sub-grade reaction obtained with a plate bearing test shall be  $5.5 \text{ Kg/cm}^3$ .

### 1.2.2 Capping layer

Capping layer is provided over the weak sub-grade to improve its load carrying capacity. Capping layer prevents sub-grade deterioration. Low quality, cheap and locally available aggregate are used in construction capping layer. Sometimes cement or lime are also used in the upper part of the sub-grade so as to enhance it's the strength and bearing capacity.

### 1.2.3 Geo-composite Drainage layer

Over a sub-grade layer a geo-composite drainage layer is provided for improved pavement drainage. It is a sand /graded gravel layer.

### 1.2.4 Dry Lean Concrete (DLC)

It is an important part of modern rigid pavement. It is a plain concrete with a large ratio of aggregate to cement than conventional concrete and generally used as a base/sub-base of rigid pavement (Central Road Research Institute,2010). The IRC specification of materials used for Dry Lean Concrete are discussed as below (MORTH section 600)

#### 1.2.4.1 Definition

- Dry lean concrete may be defined as a lean concrete with low w/c ratio i.e. dry or most commonly known as roller compacted concrete.
- ACI 207.5R-89 defines as concrete with low workability and compacted by roller. The fresh concrete layer laid should be able to support a roller while being compacted.

## 1.3 CONSTRUCTION OF BASE/ SUB-BASE

Sub-base can be constructed using following materials

- (i) Granular material
- (ii) Stabilized soil
- (iii) Semi-rigid material,

The following section contains a brief discussion on *dry lean cement* (DLC) concrete as sub-base, which is popularly being adopted for the current concrete pavement construction in India.

### 1.3.1 Dry lean cement concrete as sub-base

The thickness of DLC, generally recommended is 100mm or 150mm. As per MORT&H 2001, IRC:SP-49 1998, the requirements of dry lean concrete to be used in construction of sub-base are as under

*Aggregate to cement ratio* = 15:1

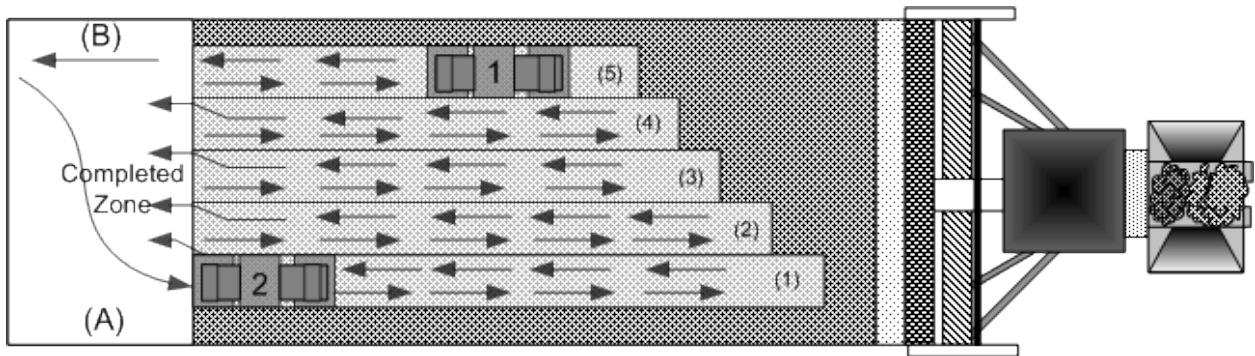
*7- day compressive strength* = >10 MPa,

The prepared sub-grade is watered to moisten the surface before laying of DLC sub-base. The material is laid uniformly and without any *segregation* with the help of a paver. The curing of

DLC is generally done by covering the surface with wet gunny bags and water is applied after regularly to keep the gunny bags wet. The construction of cement concrete pavement is started after 7 days of laying of DLC (MORT&H 2001, IRC:SP-49 1998). Figure-1.2 presents a photograph of DLC construction and Figure-1.3 presents a schematic diagram of the sequence of rolling for DLC construction.



**Figure-1.2:** Laying of DLC (*photo NHAI, Kanpur* )



(A) is the outer edge, and (B) is the inner edge of the pavement

**Figure-1.3:** Compaction Sequence For DLC ( *Photo, NHAI, Kanpur* )

### 1.3.2 Construction of concrete slab

The concrete surfacing could be made up of plain concrete or reinforced concrete. The proportions of cement, aggregate and water are determined by standard concrete mix design technique. During transporting of concrete, premature setting and segregation is avoided by continuous stirring the same. The concrete layer is spread uniformly without any segregation. Sometimes impermeable plastic/ polyethylene sheet is also laid without crumples under the

concrete slab and over the sub-base. Figure-1.4 shows laying of polyethylene sheet over dry lean concrete.



**Figure-1.4:** Laying of Polyethylene Sheet Over DLC ( *photo NHAI, Kanpur* )

### 1.3.3 Compaction and surface finishing

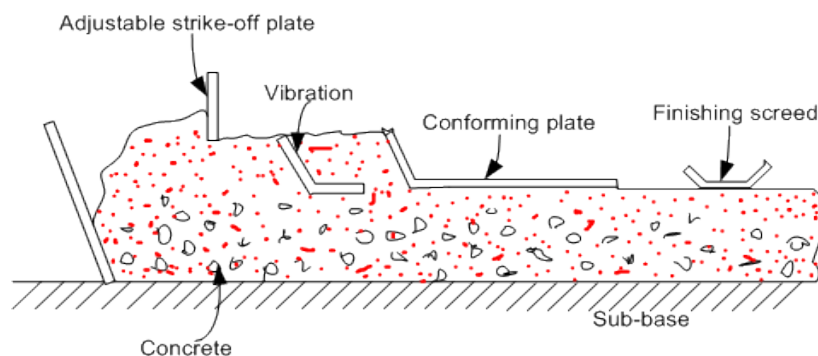
Concrete layer spread uniformly is compacted with the help of suitable equipment such that no *honey-combing* is formed, no segregation occurs and entrained air is lost ( Swanlund and Vanikar, 2002\_). The working of pavers are as following:

(i) *Fixed form paving system*

In fixed-form paver system, separate powered machines for spreading of concrete, compaction and finishing are used. The spreader spreads concrete evenly and the rotary strike-off paddles trim minor abnormalities in the surface of the concrete and adjust with the carriage-way cross-slope. The compaction-beam puts on vibration to the concrete. This vibration helps to put the dowel and tie bars at their desired positions (for a single layer construction). The wet formed joint grooves are made by vertical cut immediately after compaction and inserting a permanent strip. As an alternative, saw joint groove can be made after the concrete is sufficiently hardened and can maintain the sharp edge itself. The finishing of the surface is made with a pair of *finishing beams*. The foremost beam vibrates and smoothens the surface, and the back beam acts as *float*. The beams are oriented obliquely, it causes less damage to the joints (O'Flaherty 2002).

(ii) *Slip form paving system*

Slip-form paving machine spreads, trims, compacts and finishes the surface automatically. The slip-form paver's places dowel/ tie bars at their pre-designed locations. The *guide-wires*, are installed at fixed height on both sides of the pavement. The guide-wires helps in controlling the alignment of the slip-form paver. Correct and precise alignment of the guide-wires is extremely important in the construction of pavement. The hopper or spreader maintain a constant surcharge of the concrete above the conforming plate level. The conforming plate, vibrators, strikes off paddles and the finishing screed gives the final shape of the concrete pavement (O'Flaherty 2002). Figure-1.5 explains the operation of a typical slip-form paver, and Figure-1.6 a photograph of concrete-pavement construction by a slip form paver.



**Figure-1.5:** Schematic Diagram Explaining Operation of A Typical Slip-Form Paver



**Figure 1.6:** Construction of Concrete Pavement Slab With Slip-Form Paver (*NHAI, Kanpur*)

## 1.4- USES OF DRY LEAN CONCRETE (DLC) –COMPACTED WITH ROLLER

### 1.4.1DLC for Concrete Roads

Dry Lean Concrete with Roller Compaction was started in 1960. Economy was the mother of invention or DLC with roller compaction. The requirement for a low-cost, high-volume material for industrial pavements led to development of DLC. But today's DLC with roller

compaction has the strength to withstand loads and the durability to resist freeze-thaw damage. DLC is used in variety of paving applications such as container ports, parking lots. Compared to conventional concrete, Roller Compacted DLC placed with new high-density pavers offers high quality in terms of strength, durability, and surface finish at relatively low costs. Depending on the desired thickness and width of the installation, the concrete can be laid very quickly – from 60 to 120 m/h. It can be placed in single or multiple lifts, most typically in 150 or 200 mm (6 or 8-inch) thickness, and is particularly suitable as either a load-carrying base course or a riding surface. DLC has the same basic constituents as normal concrete, except that it has less water content and zero slump. For road construction the mix is placed through a conventional or a high-density paver and similar to asphalt and then compacted with a vibratory roller. The mix is so stiff that the vibratory roller can begin compacting immediately behind the paver. DLC is also much stronger than asphalt and can be placed thinner to achieve the desired load carrying capability. This labor and thickness reduction combined with the competitive initial material cost compared to asphalt makes DLC extremely cost effective. DLC shows minimal potholes, rutting, or shoving and can span soft localized soft sub-grades.

#### **1.4.2 DLC for Safe Dams**

DLC has three key properties that make it uniquely suited for dams: economy, performance, and high-speed construction. It has the strength and durability of conventional concrete, but at a low cost. DLC can be used to build new dams or to shore up old ones. For existing earth and rock fill dams, DLC acts like a rigid cover to protect them from the erosion of high-velocity water flows..DLC is not only more durable than earth or rock fill dams, but it's frequently more economical. DLC has also proven itself in many other types of applications. Older concrete and masonry dams can be buttressed with DLC to increase resistance to earthquake loading and to improve stability to prevent overturning and sliding. DLC is used as backfill to support conventional concrete spillways. Due to its high resistance to abrasion, it is also used to construct stilling basins, build liners for outlet channels. The first successful application of DLC compacted with roller technology was demonstrated in 1974. The repair of the collapsed intake tunnel of Tarbela Dam proved that the material had more than adequate strength and durability. The maximum placement of 18,000 m<sup>3</sup> of DLC with roller compaction in one day, which is still a world record, was a clear evidence of the potential of this new construction method.

### **1.4.3 Typical application areas of DLC**

The use of DLC for pavements at industrial facilities such as port and intermodal container terminals is particularly appropriate because of the ability to construct low-cost concrete pavements with DLC over large areas.

- Bulk material storage
- General cargo storage
- Container terminals
- Road / Rail transfer facilities
- Ro-Ro terminals
- Truck parks
- Tank roads and parking
- Sewage sludge stacking
- Composting slabs
- Pre-casting yards
- Truck parking yards made of DLC with Roller Compaction Concrete.

## **1.5- ATTRIBUTES OF DLC WITH ROLLER COMPACTION**

### **1.5.1DLC design Mix**

The objective of mix design is to produce an DLC mixture that has sufficient paste volume to coat the aggregates in the mix and to fill in the voids between them. Any of the basic DLC proportioning methods like those based on concrete consistency testing, the solid suspension model, the optimal paste volume method, and soil compaction testing may be used for mix design. Dry Lean Concrete compacted with roller uses aggregate sizes often found in conventional concrete. However, the blending of aggregates will be different than that done in case of conventional concrete. Crushed aggregates are preferable in DLC mixes due to the sharp interlocking edges of the particles, which help to reduce segregation, provide higher strengths, and better aggregate interlock at joints and cracks. Gap-graded mixes that are dominated by two or three aggregate sizes are not desirable for DLC. The content of fine particles required is typically higher than that of conventional concrete. Washed aggregates are not required for this type of concrete since a small quantity of non-plastic fines present (2% to 8% material passing a 75  $\mu\text{m}$ ) can enhance its properties. This produces a mix that is stable during rolling.

Various Standards /institutes like ACI recommend particular grading for different roller compacted structures like pavements. Generally use of dense, well-graded blends with a nominal maximum size aggregate not exceeding ¾-inch (19 mm) is recommended in order to help minimize segregation and produce a smooth finished surface. The mix should be such that the mix is dry enough to support the weight of a vibratory roller yet wet enough to ensure an even distribution of the cement paste.

Compared with conventional concrete, DLC pavement mixes have:

- ✓ A lower water content
- ✓ A lower paste content
- ✓ No air-entrainment, although some admixtures may be used to increase workability and control set time.
- ✓ More finer aggregates
- ✓ Smaller maximum size coarse aggregate.

### **1.5.2 The Curing of DLC Mix**

Curing is very important for DLC also. Since due to very less water content - there is no bleed water in DLC, the main reason is to prevent it's drying to avoid cracking resulting from drying shrinkage & to ensure adequate compressive strength by allowing hydration. Curing also helps in avoiding dusting of surface. Normally the surface of DLC is kept moist for 7days or until a curing compound is applied. Due to the open texture surface of DLC, the curing compound application rates are 1.5 to 2.0 times of application rates used for conventional concrete. In DLC pavement(due to large surface area of structures) curing techniques such as plastic sheeting and wet burlap may not be used due to higher cost involved.

## **1.6- IMPROVEMENT IN DLC PAVEMENTS**

### **1.6.1 Mineral Admixtures**

Fly Ash is the key component of DLC. Fly Ash, besides providing the critical size of fines needed to manufacture superior concrete, brings other chemical benefits and advantages to the mix design of concrete.

Replacement of Ordinary Portland Cement (OPC) with Fly Ash has the following benefits:

- Lower installed and life cycle costs versus conventional pavements.
- Provides higher strengths and greater long term durability.

- Improves workability & place-ability due to the spherical structure of Fly Ash.
- Significantly reduces Alkali Aggregate Reaction (AAR), preventing cracks.
- Improves Sulfate Attack Resistance, preventing expansion cracks, and loss of strength.
- Reduces the Heat of Hydration (by 60%) preventing thermal cracking.
- CO<sub>2</sub> is a significant by-product in the manufacture of Portland cement. Every ton of Portland cement that is replaced with Fly Ash in a concrete mixture, prevents one ton of CO<sub>2</sub> being released into the atmosphere. Appropriate production and handling of Fly Ash complements the environmental objectives of utilities and cement manufacturers. This presents an opportunity for collaboration between the utility and cement industries to "green" their respective operations and reduce costs. And as the value, allocation and trading of CO<sub>2</sub> emission credits evolve over the next several years, the recycling and responsible use of Fly Ash will contribute substantially to the environmental sustainability of industry operations.

However, in other parts of the world Class C fly ash, slag, and natural pozzolana have also been used.

### **1.6.2 Chemical Admixtures**

In DLC Air-entraining and water-reducing admixtures are used in compositions that contain higher volume of paste. Set-retarding admixtures can extend the time up to which the concrete lift should remain the unhardened, reducing the risk of cold joints with subsequence lift. In DLC mixtures of dry consistency, however, chemical admixtures show rather a limited effectiveness.

### **1.6.3 Aggregates**

Aggregates of size more than 76 mm are rarely used in manufacturing of DLC since they can cause problems in spreading and compacting the layer. The size of coarse aggregate has a major role in the degree of compaction in small layers. The use of material finer than 75 micron produces a more cohesive mixture by reducing the volume of voids.

### **1.6.4 Durability**

- The coefficient of permeability of DLC with Roller compacted is a critical parameter for long-term performance of dams, particularly if no impermeable membrane has been used at the upstream face of the dam.

- The construction process of DLC with Roller Compacted generates porous zones between the lifts where water can percolate. Depending on the mixture proportions and construction process, the coefficient of permeability can vary over magnitude of 8 orders. For instance, the lean concrete at Willow Creek dam had a coefficient of permeability of  $2 \times 10^{-4}$  m/s, while the coefficient of permeability at Upper Stillwater Dam was  $4 \times 10^{-12}$  m/s. Willow Creek Dam, since it has an impermeable membrane at its upstream face.
- If the moisture content in concrete goes beyond the critical saturation point, the performance of non-air entrained DLC to cycles of freezing and thawing will be poor; however, if the structure does not become saturated, the frost resistance of the concrete is satisfactory.

## **1.7 CONCRETE MIXTURE PROPORTIONING**

### **1.7.1 Method I**

This method uses the principles of soil compaction to produce a **Dry Lean Concrete(DLC)**, where the optimum water content of the concrete is the one that produces the maximum dry density of the mixture. This method does not utilize the conventional concept of minimizing the w/c ratio to maximize the concrete strength; the best compaction gives the best strength, and the best compaction occurs at the most wet mix that will support the operating vibrating roller. The overriding criteria for these mixtures are the compressive and shear strength since the dam using this type of concrete typically will have an impermeable upstream face made either by traditional mass concrete or precast panels.

### **1.7.2 Method II**

This method uses traditional concrete technology methods to produce high-paste of DLC mixtures. Upper Stillwater and Elk Creek Dams are examples of dams that were built using this approach. The overriding strength between the lifts and low permeability of criteria for these mixtures are the shear strength of concrete since no protective, impermeable face is used upstream This method does not utilize the conventional concept of minimizing.

### 1.7.3 Laboratory Testing

- DLC is a zero-slump concrete whose properties are strongly dependent on the mixture proportions and on the quality of compaction, Concrete is consolidated at the site using vibrating rollers.
- Despite extensive research on this subject, there is as yet no unanimously accepted methodology to simulate the field condition in preparing laboratory samples.

### 1.7.4 Construction Practice

- I. The overall planning of a DLC with roller compacted dam is conceptually different from a gravity dam. To minimize thermal stresses, traditional mass concrete is built in separate, monolith blocks.
- II. This process is slower than traditional but allows great flexibility; if a problem develops in one of the blocks, the construction front moves to another block. DLC dams do not have such luxury.
- III. The operation of DLC laying is continuous process, building one horizontal lift at a time.
- IV. Special requirements for batching and mixing of DLC are not need, using the same equipment used for conventional mass concrete.
- V. Ready-mixed concrete trucks not be used to transport DLC because zero-slump conc. is too dry and it can't be discharged.
- VI. To obtain economical benefits, special care must be taken in the selection of equipment and construction methods for fast placement and consolidation of DLC compacted with roller.
- VII. Conveyor belt systems may be an efficient method of transporting Dry Lean Concrete.
- VIII. The success of a DLC with roller compacted dam is often contingent on the correct selection of lift thickness, which depends on the mixture proportions and on the equipment available.
- IX. If the lift is too thin, the placement rates will be small, thereby reducing the advantages of using DLC.
- X. For too thick lift, the compaction will not be adequate, creating horizontal layers of higher porosity, thereby compromising the strength and durability of the structure.

- XI. Normally, the thickness of the lifts ranges from 0.150 to 0.900 m; in the U.S. a lift thickness of 0.300 m is often used.
- XII. Compaction of the lift is achieved by using a vibrating roller.
- XIII. Compaction of the lift should be performed as soon as possible, typically within 10 minutes after spreading and no more than 40 minutes after mixing.
- XIV. Once adequate compaction is achieved, good curing conditions for the finished surface are essential; the surface should be kept in a moistened condition until the next lift is placed.
- XV. The dry consistency of DLC results in difficulty in bonding fresh concrete to hardened concrete.
- XVI. This bond can be improved between the lifts can be improved by reducing the time of casting the lifts or by increasing the paste content in the mixture.
- XVII. Typically, bedding mixtures may contain 360 to 460 kg/m<sup>3</sup> of cement, 170 to 220 kg/m<sup>3</sup> of fly ash, and 4.75-mm maximum size aggregate.

### **1.7.5 Laboratory trial mixtures**

- General—It is recommended that a series of mixtures be proportioned and laboratory trial mixed to encompass the potential range of performance requirements. This practice will allow later mixture modifications or adjustments without necessarily repeating the mixture evaluation process. Final adjustments should be made based on full-sized field trial batches, preferably in a test strip or section where workability and compatibility can be observed.
- Visual examination—Several characteristics can be determined by visual examination of laboratory prepared trial mixtures. Distribution of aggregate in the mixture, cohesiveness, and tendency for segregation are observable by handling the mixture on the lab floor with shovels. The texture of the mixture (harsh, unworkable, gritty, pasty, and smooth) can be seen and felt with the hand. These characteristics should be recorded for each mixture.
- Testing—Laboratory tests, including temperature, consistency, unit weight, and air content, should be conducted on the fresh DLC produced from each trial mixture. In addition, specimens should be prepared for compressive strength testing at various ages, with various moisture content (i.e. 5.0% , 6.0% & 7.0% ) usually 7 and 28days, to indicate the strength gain characteristics of each mixture. These specimens can also

be used for determination of static modulus of elasticity and Poisson's ratio at selected ages. Additional specimens should also be fabricated for splitting tensile strength (ASTM C 496) or direct tensile strength at various ages to establish their relationship to compressive strength, and to provide parameters for use in structural analysis. On major projects, specimens for thermal properties, including adiabatic temperature rise, coefficient of thermal expansion, specific heat, and diffusivity, are usually cast from one or more selected DLC mixtures. Specimens for specialized tests such as creep, tensile strain capacity, and shear strength may also be cast from these mixtures. Many commercial laboratories are not equipped to conduct these tests, and special arrangements may be required with the Corps of Engineers, U.S. Bureau of Reclamation, or universities that have the equipment and facilities for this work.

➤ **1.8 Features of DLC**

- High flexural strength 3.5 MPa to 7.0 MPa
- High compressive strength 28 MPa to 69 MPa
- High shear strength
- High density, low absorption
- Low water content, low water/cement ratio
- Aggregate interlock
- No steel reinforcing or dowels

A typical cross-section of a designed concrete road is shown in Figure 1.1. The IRC specification of materials used for Dry Lean Concrete are discussed as below (MORTH section 600)

**1.8.1 Cement:** Any of the cements, as mentioned in Table 1.1a can be used for manufacturing dry lean concrete.

- 1) Fly ash up to 20 percent by weight of Cement may be used in 53 Grade Cement. No fly ash shall be used in any other grade of Cement other than 53 Grade.
- 2) Mix design will be done as per IRC: SP: 49. The OPC content shall not be less than  $135 \text{ kg/m}^3$  in case of blending at site. The curing period may be suitably enhanced (by at least about 2 days).

**Table1.1a:** Type of Cement

S. No.	Type	Conforming to
1	Ordinary Portland Cement	43 Grade IS:8112
2	Portland Blast Furnace Slag Cement	Furnace Slag Cement IS:455
3	Portland Pozzolana Cement	Pozzolana Cement IS:1489-Part I
4	Ordinary Portland Cement 53	Portland Cement 53 Grade IS:12269

**1.8.2 Aggregates :**Aggregates for lean concrete shall be natural material complying with IS:383. The aggregates shall not be alkali reactive. The limits of deleterious materials shall not exceed the requirements set out in IS:383. In case the Engineer considers that the aggregates are not free from dirt, the same may be washed and drained for at least 72 hours before batching, or as directed by the Engineer.

**1.8.3 Coarse Aggregates :** Coarse aggregates shall consist of clean, hard, strong, dense, non-porous and durable pieces of crushed stone or crushed gravel and shall be devoid of pieces of disintegrated stone, soft, flaky, elongated, very angular or splintery pieces. The crushed gravel/aggregate shall have at least one fracture faces. The maximum size of the coarse aggregate shall be 31.5 mm.

**1.8.4 Fine Aggregates:**The fine aggregates shall consist of clean, natural sand or crushed stone sand or a combination of the two and shall conform to IS:383 (Table 1.1b). Fine aggregate shall be free from soft particles, clay, shale, loam, cemented particles, mica, organic and other foreign matter.

**Table1.1b:** Fine aggregates (IS 383-1970)

IS SIEVE Designation	Percentage passing for			
	Grading zone I	Grading zone II	Grading zone III	Grading zone IV
10mm	100	100	100	100
4.15mm	90-100	90-100	90-100	95-100
2.36mm	60-95	75-100	85-100	90-100

1.18mm	30-70	55-90	75-100	90-100
600 micron	15-34	35-59	60-79	80-100
300 micron	5-20	8-30	12-40	15-50
150 micron	0-10	0-10	0-10	0-15

The fine aggregate shall not contain deleterious substances more than the following:

Clay lumps	1.0 percent
Coal and lignite	1.0 percent
Material passing IS Sieve No.75 micron	
i) Natural sand (Uncrushed)	3.0 percent
ii) Crushed sand	8.0 percent

The coarse and fine aggregates may be obtained in either of the following manner:

- i) In separate nominal sizes of coarse and fine aggregates and mixed together intimately before use.
- ii) Separately as 31.5 mm nominal, 25 mm nominal single size, 12.5 mm nominal size graded aggregates and fine aggregate of crushed stone dust or sand or a combination of these three. They shall be mixed together in prescribed proportion before use.
- iii) Combined flakiness and elongation index shall not be more than 35 percent. The material after blending shall conform to the grading as indicated in Table 1.1c

### **1.8.5 Proportioning of Materials for the Mix**

The mix shall be proportioned with a maximum aggregate cement ratio of 15: 1. The water content shall be adjusted to the optimum for facilitating compaction by rolling.

**1.8.5.1 Cement Content:** The minimum cement content in the lean concrete shall be 150 kg/m<sup>3</sup> of concrete. In case fly ash is blended at site as part replacement of cement, the quantity of fly ash shall not be more than 20 % by weight of OPC cement and the content of OPC shall not be less than 135 kg/m<sup>3</sup>. If this minimum cement content is not sufficient to produce concrete of the specified strength.

**Table1.1c: Aggregate Gradation for Dry Lean Concrete**

<b>Sieve Designation</b>	<b>Percentage by weight passing the Sieve</b>
31.5 mm	100
26.50 mm	90-95
19.0 mm	80-90
9.50 mm	55-75
4.75 mm	35-60
600.00 micron	10-35
75.00 micron	0-8

**1.8.5.2 Concrete Strength :**The average compressive strength of each consecutive group of 3 cubes made shall not be less than 10 MPa at 7 days. In addition, the minimum compressive strength of any individual cube shall not be less than 7.5 MPa at 7 days.

**1.8.6 Paving Quality Concrete (PQC):** The IRC specifications of materials used for Pavement Quality Concrete(PQC) are discussed as below (MORTH section 600).

## **1.9 GENERAL OVERVIEW ON THE USE OF SLAG IN ROAD CONSTRUCTION**

Slag has been used in construction activities for a very long time. Slag was used for roads and wall making during the Roman period. In the early 19<sup>th</sup> century, slag was used to produce slag cement and also used rail ballast and for building bridges. During that time also, the casting of molten slag, the production of slag sand, the production of bricks and mortar and the manufacture of slag wool were introduced from blast furnace slag.(*Yusof,2006* )

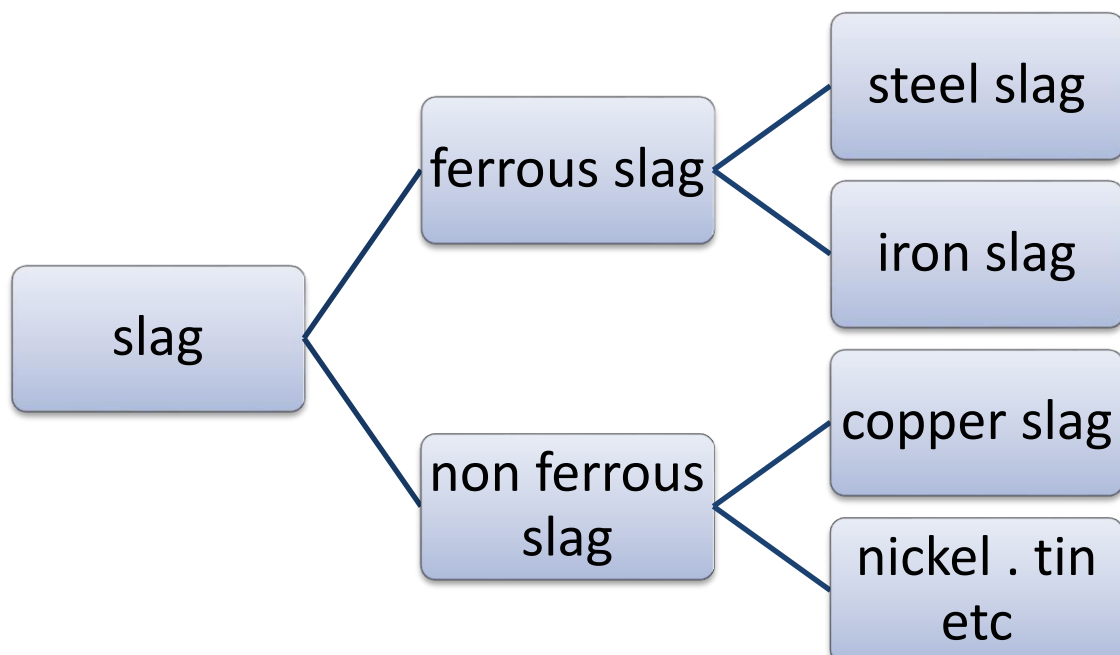
In general, slag can be divided into two categories, non-ferrous and ferrous slag . The various types of slag products have different properties and characteristics. The properties and characteristics of slag are very dependent on how they are processed during the making of the main products. Ferrous slag is produced during the refining of ferrous metal such as iron and steel. Blast furnace slag arises during the production of iron while steel slag is produced during the production of steel. Blast furnace slag and steel slag can be produced in

granulated, pelletized or air-cooled form. Blast furnace slag has been used for many years and in many areas. Blast furnace slag is used as a high quality material in the cement industry, in glass making, concrete block manufacture and for road-stone application. On the other hand, steel slag has more limited application.

Non-ferrous slag is produced during the recovery and processing of non-ferrous metal from natural ore. The slag is a molten by-product of high temperature processes that is primarily used to separate the metal and non-metal constituents contained in the bulk ore. When cooled, the molten slag converts to a rocklike or granular material. Examples of non-ferrous slag are copper, tin, nickel, lead, zinc and phosphorus slag.

There are many factors that influence the success of recycling of these materials. The relative importance varies from country to country but typically includes the following: -

- The public is becoming more aware about the environment.
- Non-availability of virgin aggregates.
- Public against to aggregate quarrying.
- Public against to land-filling.
- Government policy to minimize the use of natural aggregate and promote the use of recycled materials as alternative aggregates.
- Govt. Introduces aggregate taxes to encourage recycling and utilization of secondary material.
- Introduction of landfill taxation to stimulate waste reduction and re-use.



**Figure 1.7:**Types of Slag (Typical)

## 1.10. COPPER SLAG

### 1.10.1 Production of Copper Slag (Yusof, 2006)

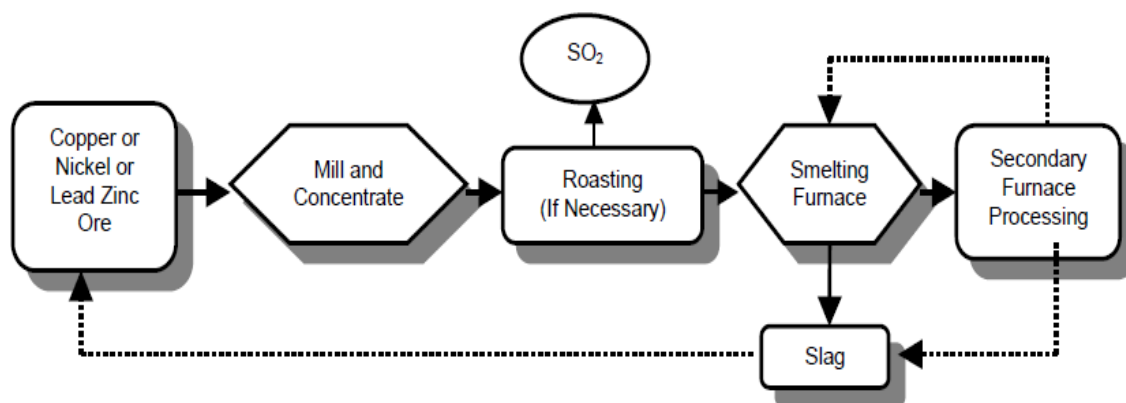
In the early days of copper mining, high-grade oxidized ores were smelted directly in blast furnaces. However, the copper content of the slag was quite high while the produced copper was impure and required further refining. General manufacturing process for copper, nickel and lead-zinc slag production is shown in figure 1.7. Eventually, the practice of smelting in blast furnaces was abandoned. Currently, the production of copper slag and also nickel slag do not differ much. Both of them are produced by three operations

- Roasting, in which sulphur in the ore is eliminated as sulphur dioxide ( $\text{SO}_2$ );
- Smelting, in which the roasted product is melted in a siliceous flux and the metal is reduced;

### 1.10.2 Copper Slag Properties

#### a) Physical Properties

Air-cooled copper slag has a dull black colour and a glassy appearance. Granulated copper slag is more vesicular and porous and therefore has lower specific gravity and higher absorption than air-cooled copper slag. In general, the specific gravity of copper slag will vary with its iron content. The unit weight of copper slag is somewhat higher than that of conventional aggregate. The absorption of the material is typically very low. Some of the physical properties of copper slag are shown below Table 1.2a



**Figure 1.8:** General Manufacturing Process For Copper, Nickel And Lead-Zinc Slag Production (Yusof, 2006)

**Table 1.2a : Typical physical properties of copper slag** (*Mineral Research & Recovery Inc. 2001*)

Properties	Value
Specific gravity	3.4 – 3.6
Bulk density, kg/m <sup>3</sup>	1762 – 1922
Water absorption (% by mass)	0.13

**b) Chemical Properties**

Copper slag is mainly a ferrous silicate. Other chemical properties are in Table 1.2b

**Table 1.2b : Typical chemical properties of Copper slag** (*Mineral Research & Recovery Inc. 2001*)

Properties	Value (%)
Calcium oxide ( CaO)	5.94
Silicon dioxide (SiO <sub>2</sub> )	38.92
Aluminium oxide (Al <sub>2</sub> O <sub>3</sub> )	9.45
Magnesium oxide (MgO)	0.13
Iron (FeO or Fe <sub>2</sub> O <sub>3</sub> )	32.11
Manganese oxide (MnO)	0.13
Sulfur (S)	2.27
Sodium oxide (Na <sub>2</sub> O)	0.13
Potassium oxide (K <sub>2</sub> O)	0.17

**1.10.3 The Use of Copper Slag in Road Construction** (*Yusof, 2006* )

At an early stage the use of Copper slag and Nickel slag aggregate as a granular base was took place in the mining road, where this slag was produced. It has demonstrated satisfactory performance in what are generally considered to be very severe traffic and operating

conditions. Copper and Nickel slag have been used as granular base and embankment materials, aggregate substitutes in hot mix asphalt, mine backfill material, railway ballast material, grit ballast abrasives, roofing granule material, and in the manufacture of blended cements.

The uses of copper slag with asphaltic and ordinary Portland cement concrete has been discontinued as a result of environmental interests. The discontinuation has nothing to do with the materials, workability or strengths. There are very limited toxicity testing data which indicate the quality of the leachate from specific copper slag.

Copper slag has also been used for cement material, sand blasting and reclamation. It is also possible to use a copper slag as a concrete aggregate although there are some problems which still require solutions from researchers.

#### **1.10.4 Problems that Arise from the Use of Copper Slag in Road Construction**(*Yusof, 2006*)

The most pressing issue that needs to be resolved when using the slag is the environmental suitability of copper slag in road construction application. Materials from each source must be assessed for heavy metals content and leach ability.

There also are some problems in using copper slag as a concrete aggregate. One of the problems is excess bleeding attributed to the glassy surface of the copper slag.

Another problem is the delay of setting time of concrete with copper slag where in some cases it takes more than one week. However the delay of setting time does not have a negative influence on the durability of concrete with copper slag.

## 2.1 GENERAL

Various researchers have worked on use of ferrous and non ferrous slag in concrete. **Wang et al (1996)** reported the philosophy and technology of slag utilization. The paper presents that the criteria developed for use of slag as a granular material and as an aggregate in concrete are reliable and practical in use. To correctly utilize slag in highway construction and ensure that it is technically sound and durable, the following steps have to be followed:

- (i) select the right criterion for a specific use;
- (ii) conduct relevant laboratory testing to quantify the given sample;
- (iii) determine the usability based on relevant criterion;
- (iv) conduct field quality control; and
- (v) monitor long term performance, which are the same as the use of normal natural materials.

The mechanical strength and durability of concrete vary with the use of various slag. The use of slag as a natural aggregates in concrete and as a partially replacement for cement are both acceptable to a reasonably large extent.

A detailed review of the literature regarding the mechanical properties and durability aspect of various slag mix concrete pavements is presented in succeeding section.

## 2.2 Easwary P. and J.P. Annie Sweetlin (2016)

The authors investigated the behavior of PQC- DLC slab subjected to stationary load. It was experiential that load deflection pattern for multi-layered slabs come into view to be equally ductile when compared with PQC slabs but are less stiff in terms of load carrying capacity. As the DLC is a part of the roadway, a composite and economical cement-concrete-pavement can be designed. Among the multi-layered slabs tested, equal layer thickness of Pavement Quality Concrete and Dry Lean Concrete (37.5mm each) yield the similar load carrying capacity as that of Pavement Quality Concrete(PQC) slab of 75mm thick( Reference slab). However the multi-layered slab with 25mm Pavement Quality Concrete (PQC) satisfies the requirement of IRC 58 – 2001 in terms of stress (4.0 MPa). It is concluded that multi-layered slabs with DLC and PQC combination is technically viable and economically feasible.

### 2.3 Patnaik Binaya et al (2015)

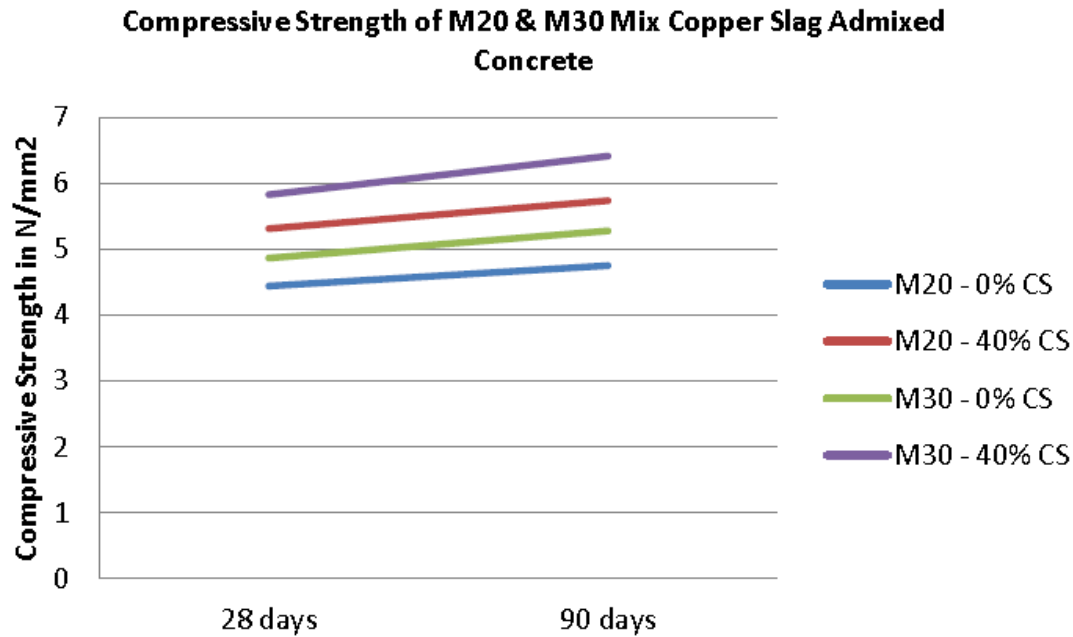
The author investigated the properties, strength and durability of concrete have copper slag as a partial-replacement of fine aggregate. Author used Concrete-Grade M20 and M30 with different copper slag replacement from 0% to 50% in the concrete. Properties Strength and Durability such as Split Tensile Strength, Compressive Strength, Acid Resistivity, Flexural Strength and Sulphate Resistivity were evaluated for the mixes of concrete. The outcome shows that the strength-properties of material has improved having copper slag as a partial replacement of fine aggregates upto 40% in concrete .It is also concluded that concrete has low resistant to acid-attack and higher resistance against Sulphate-attack.

**Table 2.1:** Concrete Mix Design Details – M20 and M30 Mix –Patnaik Binaya et al 2015

Grade	% of Copper Slag	Cement in kg	Fine Aggregate in kg			20mm Metal in kg	Water in kg
			Natural Sand	Copper Slag	Total FA		
M20	0%	320	712	0	712	1178	176
	40%	320	640.8	71.2	712	1178	176
M30	0%	350	703.6	0	703.6	1164	175
	40%	350	422.16	281.44	703.6	1164	175

**Table 2.2:** Compressive Strength of M20 and M30 Mix Copper Slag Admixed concrete – Patnaik Binaya et al 2015

Grade of Concrete	Days	Compressive Strength (N/mm <sup>2</sup> )	
		0% Copper Slag Replacement	40% Copper Slag Replacement
M20	28	36.8	41.05
	90	44.34	55.17
M30	28	41.16	47.41
	90	51.28	57.24



**Figure. 2.1:** Compressive Strength - M20 & M30 Grade Mix with 0 % and 40 % of Copper Slag Replacement at 28 and 90 days—Patnaik Binaya et al 2015

#### 2.4 Patil M. V. (2015)

The author investigated that as with the increases percentage of copper-slag, workability also increases and maximum compressive-strength of concrete increased by 34% at 20%. Replacement of fine aggregate and up to 80% replacement of copper slag concrete mix gain more strength than standard concrete strength. It is also observed that all replacements of Fine aggregate by copper slag the flexural strength of concrete is more than control mix. Compressive strength and flexural Strength is greater than before due to high hardness of copper-slag. As the proportion of Copper slag increases the density of concrete is increased. Density is improved by 7.0% due to replacement of fine aggregate at 100%. Replacement of copper-slag(CS) in fine aggregate decreases the cost of concrete produce. Author used M30 grade mix for his experimental works as a control mix.

**Table 2.3:** Compressive Strength, Patil M V 2015

Mix	Compressive Strength (( MPa)		
	7days	28 days	56days
Normal M-30	23.87	36.15	36.12
CS 10%	27.52	39.17	37.43
CS 20%	32.45	47.29	47.75
CS 30%	30.89	39.22	43.48
CS 40%	27.48	37.01	42.25
CS 50%	29.50	38.53	42.37
CS 60%	30.12	42.89	43.21
CS 80%	27.17	34.88	36.21
CS 100%	20.63	31.04	33.31

**Table 2.4:** Density of Concrete, Patil M V 2015

Mix	28 days Density N/m <sup>3</sup>	Density gained % 28 days
Normal M-30	2578.95	00.00
CS 10%	2617.11	+1.51
CS 20%	2643.87	+2.52
CS 30%	2682.03	+4.03
CS 40%	2694.51	+4.50
CS 50%	2706.99	+4.96
CS 60%	2714.98	+5.27
CS 70%	2721.41	+5.55
CS 80%	2729.07	+5.86
CS 90%	2735.48	+6.09
CS 100%	2741.65	+6.32

### 2.5 Singh Thongam et al (2014)

The author Studied the effects on concrete-mix properties by partial replacement of natural sand with copper slag by 10%, 20%, 30%, 40%, 50% and 60%. Author used M30 grade concrete measured to study the strength parameters, compressive and flexural strength after curing of 3, 7 and 28 days. The outcome from cube(150X150X150mm) compressive strength, static flexural strength test have shows that the strength increases with increase the percentage replacement of copper-slag by the weight of natural sand was up-to replacement of 40%. The compressive strength and flexural strength after 28 days curing was increased by 31.6% to 54.87% and 10.87% to 26.62% respectively with substitution of copper slag.

**Table 2.5:** Properties of Fine Aggregates And Copper Slag – Singh Thongam et al 2014

<b>Properties</b>	<b>Fine aggregates</b>	<b>Copper slag</b>
Specific Gravity	2.53	3.57
Water absorption %	0.80	0.14
Moisture content %	0.50	0.10
Fineness modulus	2.55	2.68
Bulk density g/cc	1.67	0.14
Grading Zone	Zone II	Zone II

**Table 2.6:** Mix Proportions Details (In Kg/m<sup>3</sup>) Considered In Studies – Singh Thongam et al 2014

<b>Mix Materials</b>	<b>CC</b>	<b>Mix-1</b>	<b>Mix-2</b>	<b>Mix-3</b>	<b>Mix-4</b>	<b>Mix-5</b>
Cement	414	414	414	414	414	414
Coarse aggregates	1129	1129	1129	1129	1129	1129
Fine aggregates	638	574	510	446	382	319
Copper slag	0	90	180	270	360	450
Water	186	186	186	186	186	186

**Table 2.7:** Compressive Strength Test Results– Singh Thongam et al 2014

<b>Mix Designation</b>	<b>Avg. Compressive Strength in N/mm<sup>2</sup> at Curing Period</b>			<b>Percentage Strength Gain at 28days</b>
	<b>3days</b>	<b>7days</b>	<b>28days</b>	
CC	17.44	27.61	35.23	-
Mix-1	19.77	30.16	46.36	31.60
Mix-2	23.25	30.66	47.12	33.75

Mix-3	25.29	32.77	48.77	38.43
Mix-4	26.81	34.95	54.56	54.87
Mix-5	24.56	30.23	51.63	46.55
Mix-6	4.73	6.53	8.87	10.87

## 2.6 Akshay C. Sankh, Praveen M. Biradar et al (2014)

Sand is a prime material used for preparation of mortar and concrete and which plays a major role in mix design. This paper presents a review of the different alternatives to natural sand in preparation of mortar and concrete. By adding of copper slag, compressive, split tensile and flexural strength(21% to 51%) of concrete is increases. The density of conc. increases with replacement of copper slag(CS) in concrete. By partial replacement of sand by copper slag, the strength increase is observed up to 40% replacement. CS replacement at higher level leads to segregation and bleeding due to less water absorption capacity of copper slag.

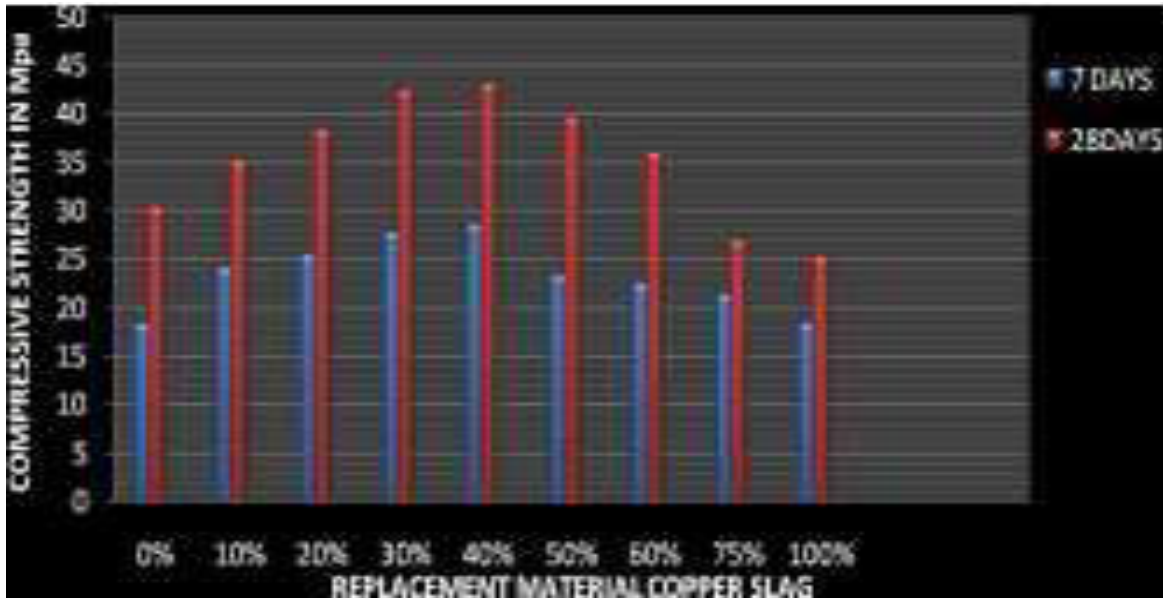
## 2.7 ChavanR Rand KulkarniD B (2013)

The author Studied the effect of using copper slag as a replacement of natural sand on the strength properties. Author used M25 grade concrete and tests conducted for copper slag replacement with sand from 0% to 100% in concrete. The results were compared with control-mix concrete prepared with OPC cement and sand without copper slag. It concluded that Compressive Strength increase with replacement of sand with copper slag even at 100% replacement but best result at 40% replacement after 28 days curing. Highest Compressive strength increased 55% at 40% replacement of sand by copper slag and upto 75% replacement, concrete gain additional strength than control mix. It is also observed that for all replacements, percentage of sand by Copper slag the compressive and flexural strength of concrete is more than standard mix.

**Table 2.8:** Compressive Strength with various percentage of Copper Slag -Chavan R. R.and Kulkarni D. B. 2013

<b>Mix</b>	<b>Avg. Compressive Strength in N/mm<sup>2</sup> at Curing Period 7days</b>	<b>% Compressive Strength Gained at 7 days</b>	<b>Avg. Compressive Strength in N/mm<sup>2</sup> at Curing Period 28 days</b>	<b>% Compressive Strength Gained at 28 days</b>
M-25	18.29	100.00	30.36	100.00
CS 20%	25.43	139.03	38.22	125.88
CS 40%	28.48	155.71	43.01	141.67
CS 60%	22.37	122.30	35.89	188.21
CS 75%	21.21	155.96	26.88	88.53
CS 100%	18.31	100.10	25.14	82.80

Table 2.8 shows that maximum strength increases upto 155.96% at 7 days curing from control-mix strength, where Copper Slag 75% replaced with fine aggregates and compressive strength increases upto 188.21% after 28 days curing where 60% copper slag is replaced with fine aggregates. Table 2.8 shows that compressive strength is decreases with more addition of copper slag in the mix. Study shows 60% or 40% replacement of fine aggregates with copper slag is reasonable, beyond this percentage there is no use of replacement.



**Figure 2.2:** Compressive Strengths results for copper Slag- Chavan R Rand Kulkarni D B 2013

### 2.8 Kumar Binod (2013)

The author studied the feasibility of using copper slag, as a partial replacement of sand in the making of DLC mixes. A control mix for Pavement Quality Concrete was prepared with 400 kg/m<sup>3</sup> of Portland Cement and water/cement ratio of 0.40. Trial Sample were prepared by replacing of 20%, 40%, 60%, 80% and 100% copper slag with sand in Standard mix. Bleeding and Workability of concrete, flexural and compressive strength at 7 and 28 days, abrasion resistance and drying shrinkage were measured for all the mixes. Dry Lean Concrete mixes were designed with 150 kg/m<sup>3</sup> of OPC Cement and different blend of stone-dust used with 20%, 40%, 60% and 80% copper slag as fine aggregate. Dry Lean Concrete mixes were then prepared with different water contents to find-out the optimum water content for achieve highest density, and corresponding compressive strength at 7 and 28 days for each sample of stone-dust and copper slag. The laboratory test results indicates that the compressive strength of Pavement Quality Concrete at 7days and 28days was not affected by addition of copper slag as fine aggregate in any concrete mix. Small gradual addition to flexural strength at 28days was seen with addition of copper slag. Drying shrinkage of PQC decreases with increase of copper slag and decrease stone dust. Abrasion resistance of concrete mixes containing copper slag was less as compare to non-slag concrete. Compressive strength of Dry Lean Concrete decrease with increase of copper slag beyond 40%. Compressive strength and other requirements of Pavement Quality Concrete for example, segregation, cohesiveness, finishing, shrinkage, texturing and abrasion resistance, it

concluded that the mix of stone dust with copper-slag upto 40% can be used as fine aggregate for PQC as well as DLC.

**Table 2.9:**Mix proportions for DLC. -Kumar Binod 2013

Ingredients	Proportions (kg/m <sup>3</sup> )				
	D0	D20	D40	D60	D80
Cement	150	150	150	150	150
Copper slag	–	194	388	581	775
Stone dust	720	576	432	288	144
Crushed stone	1080	1080	1080	1080	1080

Table 2.9 shows the various DLC mixtures designed with 150 kg/m<sup>3</sup> with various blends of stone-dust (i.e 20%, 40%, 60% and 80% ) with copper slag as sand.

**Table 2.10:** Density and compressive strength of DLC. - Kumar Binod 2013

Mix Designation	Water Content(%)	Density (kg/m <sup>3</sup> )	Compressive strength	
			7 days	28 days
D0	5.0	2467	12.4	16.1
	5.5	2502	14.6	18.7
	6.0	2587	16.9	21.4
	6.5	2532	15.7	20.4
	7.0	2510	13.2	16.5
D20	5.0	2619	15.6	19.7
	5.5	2685	18.9	22.8
	6.0	2678	17.6	21.1
	6.5	2620	14.6	18.4

	7.0	2595	13.2	16.7
D40	5.0	2700	15.7	19.1
	5.5	2729	19.6	23.7
	6.0	2691	17.1	20.6
	6.5	2675	14.8	19.5
	7.0	2667	12.2	15.1
D60	4.5	2648	16.8	20.3
	5.0	2765	19.1	23.8
	5.5	2745	17.7	20.6
	6.0	2738	16.8	19.8
	6.5	2722	13.9	17.8
	7.0	2715	11.0	14.7
D80	4.5	2778	15.4	19.0
	5.0	2833	17.9	22.1
	5.5	2763	16.2	20.9
	6.0	2721	12.1	15.8
	6.5	2713	10.6	13.5
	7.0	2704	8.8	11.5

Table 2.10 shows the effect of water content (varies from 4.5 to 7.0%) on compressive strength and Density of various Dry Lean Concrete mixtures of stone-dust with copper slag as sand.

### **2.9 Alnuaimi A. S. ( 2012)**

The author investigated on RC slender by replacement of fine aggregates (FA) with copper slag (CS). He studied with cement, water and coarse aggregate were kept constant within the

mixture, while the percentage of copper-slag replaced with sand (varied from 0 to 100%). The results showed that the substitution of up to 40% of the sand with copper-slag caused no major change in concrete strength but increasing of the percentage of CS reduces the compressive strength of the concrete and increases the slump of concrete, lateral and vertical deflections of the column. The maximum difference in compressive strength of concrete between the mixes of 0% CS and 100% CS was 29%. The failure loads of all specimens varied between 91.00% - 100.02%. Columns with more than 60 percent of copper slag experienced buckling at lower loading than those with lower percentages of copper slag. The Density of Mix is increases with increase of CS from 0% to 100 %.

**Table 2.11:**Concrete mix design quantities (kg/m<sup>3</sup>) – Alnuaimi A.S. 2012

Component	0% CS	20% CS	40% CS	60% CS	80% CS	100% CS
Water	226.7	226.7	226.7	226.7	226.7	226.7
Cement	384.3	384.3	384.3	384.3	384.3	384.3
10mm Agg.	1136	1136	1136	1136	1136	1136
Fine Agg.	712.6	570.1	427.56	285.04	142.52	0
Copper slag	0	142.5	285.04	427.56	570.1	712.6

Table 2.11 Shows the replacement of Copper slag (varies from 0 to 100%) with fine aggregates while all other contents kept same.

**Table 2.12:** Comparison of density and compressive strength of Mixes , - Alnuaimi A.S. 2012

Sr. No	Mix	0% CS	20% CS	40% CS	60% CS	80% CS	100% CS
1.	Slump (mm)	43.33	44.00	58.33	85.00	Collapsed	Collapsed
2.	Density (kg/m <sup>3</sup> )	2416	2432	2480	2516	2550	2604
3.	Comp. Strength of cube (N/mm <sup>2</sup> )	36.56	35.04	33.44	31.98	30.62	48.44
4.	Comp. Strength of Cylinder (N/mm <sup>2</sup> )	31.13	29.33	24.33	25.97	23.77	22.53

Table 2.12 shows the comparison of slump, density, compressive strength of cubes and cylinders with the replacement of copper slag in various percentages from 0 to 100%.

### 2.10 Kokubu K et al (1995)

The author studied from the experimental work presented in his paper, that the relationship between energy of compaction to the filled volume ratio is used to evaluate the efficiency of compaction and to calculate the best possible mix composition. The experimental works presented in his studies the subsequent conclusions are offered. The evaluation of the compaction characteristics of R.C.C. Concrete shows that the maximum compaction ( $y_f$ ) is achieved by vibrating concrete at low acceleration. Further than 25g the maximum compaction does not change. Evaluation of concrete by the compaction-energy calculated from the parameters used in the vibrating-table, shown that frequency of vibrations does not influence the maximum value of 'final-filled volume'. The Marshall-Hammer method produces assessable degradation of aggregates during compaction. Therefore more studies are required to review the suitability of this test. It shows that the fine aggregate content of concrete expressed as the ratio of Fine and coarse aggregate, and the water-content are the most significant mix proportioning constraint for the optimal mix proportioning of RCC - concrete.

**Table 2.13:**Compaction properties of RCC concrete -Kokubu K et al 1995

Sr. No.	Parameter	Water/ Cement Ratio		
		00.30	00.35	00.40
1	Initial filled volume	77.20	77.30	78.80
2	Compaction efficiency	00.10	00.10	00.09
3	Final field volume %	100.50	101.00	102.30
4	Compactive effort	01.13	00.81	00.80

Table 2.13 shows the effect of w/c ratio on the compatibility of concrete with s/a=38.5% and total water content of 110 kg/m<sup>3</sup>

### **3.1 General**

This test procedures of compressive strength and density of dry lean concrete containing copper slag as partial replacement of sand have been described in this chapter. The test results of various constituent materials in manufacturing dry lean concrete have also been presented this chapter.

### **3.2 Material Properties**

Cement, natural sand, coarse aggregates, copper Slag and water were used to prepare dry lean concrete. The specimens of various sizes were cast to investigate density and compressive strength of copper slag dry lean concrete. The physical properties of various materials used are presented in the subsequent sections.

#### **3.2.1 Cement**

Ordinary Portland cement of grade –43 under industrial name (SHREE ULTRA OPC 43 GRADE) conforming to Indian standard (IS:-8112 -1997) used in the current study. The test results of cement are specified in Table 3.1.

##### *Consistency*

Consistency of Ordinary Portland cement of grade –43 was found as per BIS: 4031–1988. 500 gram of Ordinary Portland cement was taken for determining its consistency. Trial paste of cement was prepared with some quantity of water and then the cement paste was placed in Vicat mould. Vicat mould filled with paste was then vibrated gently to expel the air and top surface of cement paste was leveled. The trial paste sample was placed below the plunger of Vicat apparatus in such a way that it touches the top surface of paste. Then the plunger was quickly released to penetrate in to cement paste. This procedure was repeated until the plunger to penetrate to a point 5 to 7 mm from the bottom of the mould. Different trial pastes with variable water percentages were tested until water percentages required for making up the standard consistency was determined.

*Setting times* - Setting times of Ordinary Portland cement of grade –43 was found as per BIS: 4031-1988. Paste of Ordinary Portland cement was prepared by using 0.85 times the water

required for standard consistency. Then the cement paste sample was placed in Vicatmould. Vicat mould filled with cement paste was then vibrated gently to expel the air and top surface of cement paste was leveled. The trial paste sample was placed below the needle of Vicat apparatus in such a way that it touches the top surface of paste. Then needle was quickly released to penetrate in to the cement paste. This process was repeated until the needle failed to penetrate to a point  $5.0 \pm 0.5$  mm from the bottom of the mould. The period elapsed between the time after adding water to the cement and the time at which the needle failed to penetrate to a point  $5.0 \pm 0.5$  mm from the bottom of the mould was recorded as the initial setting time.

The period elapsed between the time after adding water to the cement and the time at which the needle made an impression on the surface of test block while the attachment failed to do so was recorded as the final setting time.

#### *Compressive strength*

Cement specimens of size 69.5 x 69.5 x 69.5 mm were cast for determining the compressive strength of Ordinary Portlandcement. Cement sand paste was made by using standard sand in 1:3 cement-sand mix ratio. The constituents used inthis study for making of cement sand pasteare given as below:

Cement = 200 gram

Standard Sand = 600 gram

Water =  $(P/4 + 3.0)$  percent of combined mass of cement and sand,

Where,

P = thewater percentage (standard consistency).

Specimens were compacted with the help of vibrating machine for two minutes. The cube specimens were de-moulded after 24 hour of adding water to cement sand mixture. Then specimens were cured in water up to the age of test. Compressive strength found at 3, 7, and 28 days of curing age.

**Table 3.1:** Physical properties of Ordinary Portland Cement as per IS 8112-1997

S. No.	Characteristics	Units	Values obtained	Values as per IS 8112-1997
1.	Consistency	%	28.0	-
2.	Initial setting time	Minutes	72	Not less than 30

3.	Final setting time	Minutes	210	Not greater than 600
4.	Fineness	%	1.5	less than 10%
5.	Specific gravity	gm/cc	3.0	-
6.	Compressive Strength	(MPa)		
	3 days		24.5	23
	7 days		35.8	33
	28 days		45.6	43

### 3.2.2 Fine Aggregates

The fine aggregate (sand) conforming to grading zone II of BIS 363-1959 used in the present study was procured locally from Patiala. The sand was passed through 4.75 mm sieve before use in manufacturing of concrete specimens. The sieve analysis and physical properties of sand are listed in Tables 3.2. & Table 3.3

**Table 3.2a:** Sieve Analysis of Fine Aggregates

Sr. No.	Sieve No.	Weight retained (grams)	Cumulative Weight retained (grams)	Cumulative Percentage retained (%)	Percentage Passing (%)	Limits of zone II as per IS-383
1.	4.75 mm	0.00	0.00	0.00	100.00	90-100
2.	2.36 mm	83.50	83.50	8.35	91.65	75-100
3.	1.18 mm	129.00	212.50	21.25	78.75	55-90
4.	600 $\mu$ m	234.00	446.50	44.65	55.35	35-59
5.	300 $\mu$ m	276.00	722.50	72.25	27.75	8-30
6.	150 $\mu$ m	257.00	979.50	97.95	2.05	0-10
7.	Pan	20.50	1000.00	---	-	-
$\Sigma F = 244.45$ $F M = \Sigma F / 100 = 2.44$ (Medium Coarse)						

**Table 3.2b:** Physical properties of fine aggregates

Sr. No.	Characteristics	Property
1.	Type	Natural sand
2.	Specific Gravity	2.65
3.	Fineness Modulus	2.44
4.	Type of Sand	Medium Coarse
5	Grading Zone	Type II
6	Water absorption	1.45%

### 3.2.3 Natural Coarse Aggregate

The crushed coarse aggregate of maximum size of 20 mm was used in the current work. The coarse aggregate was procured locally from Patiala market. The results of sieve analysis of the coarse aggregate are presented in Table 3.4

**Table 3.3a:** Sieve Analysis of 10 mm Coarse aggregates

SIEVE SIZE in mm	WEIGHT RETAINED	WEIGHT RETAINED (CUMULATIVE)	PERCENTAGE RETAINED	PERCENTAGE PASSING
26.5	0.00	0	0.00	100.00
19	0.00	0	0.00	100.00
9.5	606.00	606	20.20	79.80
4.75	2111.50	2717.5	90.58	9.42
0.6	282.50	3000	100.00	0.00
0.075	0.00	3000	100.00	0.00
Pan	0.00	3000	100.00	0.00

**Table 3.3b: Sieve Analysis of 20 mm Coarse aggregates**

SIEVE SIZE in mm	Wt. Retained	WEIGHT RETAINED (CUMULATIVE)	PERCENTAGE RETAINED	PERCENTAGE PASSING
26.5	0.00	0	0	100
19	333.00	333.00	11.10	88.90
9.5	2570.00	2903	96.77	3.23
4.7	74.00	2977	99.23	0.77
0.6	23.00	3000	100.00	0.00
0.075	0.00	3000	100.00	0.00
Pan	0.00	3000	100.00	0.00

**Table 3.4: Sieve analysis of Blended aggregates**

IS Sieve mm	Individual Gradation			Combined Gradation			All In Aggregate		Limits(Morth)	
	20mm	10mm	sand	20m m	10mm	sand	Combi ned	Ideal	Lower	Upper
				38.0%	20.0%	42.0 %				
26.50	100.00	100.00	100	38.0	20.0	42	100.00	100.00	100	100
19.00	88.90	100.00	100	33.78	20.0	42	95.78	90.00	80	100
9.50	3.23	79.80	100.00	1.23	15.96	42	59.19	65.00	55	75
4.75	0.77	9.42	100.00	0.29	1.88	42	44.17	47.50	35	60
0.60	0.00	0.00	55.35	0.0	0.0	23.25	23.25	22.50	10	35
0.075	0.00	0.00	0.20	0.0	0.0	0.08	0.08	4.00	0	8

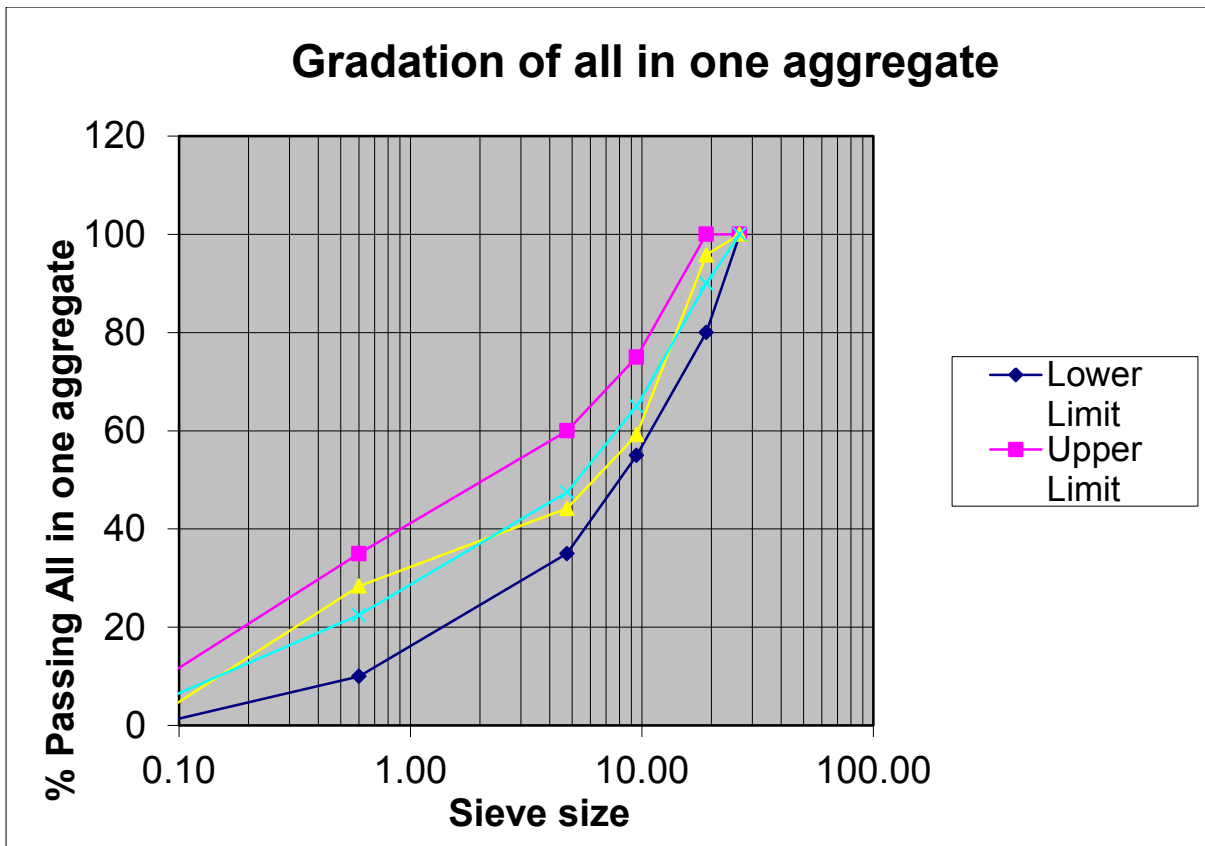


Figure 3.1: Gradation of All In One Aggregates

### 3.2.4 Copper Slag

The chemical properties and physical of copper-slag particles are presented in Table 3.5 and Table 3.6, respectively. As shown in Figure 3.1, copper slag is black in colour and its particle size is similar to that of sand. The specific gravity of copper-slag used in this work was 3.58. The water absorption of copper-slag was 1.19%. Fineness Modulus of copper slag was 2.19. The sieve analysis of copper slag is illustrated in Table 3.7. The physical appearance of copper slag is similar to sand. About 35% Silicon oxide commonly known as quartz and 55% iron oxide content was present in copper slag. The fineness of copper-slag was calculate as  $125\text{m}^2/\text{kg}$ .

Worldwide, about 33 million tons of copper slag is produced annually. About 6 to 6.5 million tons of copper slag is produced in India. Khalifa et al (2011) observed that copper-slag can be used as 50.0% replacement of natural sand to manufacture mortar and concrete. Central Road Research Institute (CRRI) carried out study on use of copper slag as replacement of sand in concrete and reported that copper-slag can be used as a partial replacement of sand up to 50.0% in pavement concrete without loss of compressive and flexural strength. CRRI in their

study revealed that concrete incorporating copper slag exhibited upto 20 % higher strength than conventional concrete.



**Plate 3.1:** Copper slag Used in this Study

**Table 3.5:** Chemical and Physical Properties of Copper Slag

<b>Chemical Composition</b>	
Al <sub>2</sub> O <sub>3</sub>	3.01%
TiO <sub>2</sub>	0.60%
Fe <sub>2</sub> O <sub>3</sub>	55.00%
SiO <sub>2</sub>	35.00%
CaO	0.20%
MgO	0.90%
K <sub>2</sub> O	1.02%
Na <sub>2</sub> O	0.95%

Cu	0.42%
----	-------

**Table 3.6:** Physical Properties of Copper Slag (Laboratory Testing)

Sr. No.	Characteristics	Value
1.	Type	Factory Wastage
2.	Bulk Density	3.54 gm/cc
3.	Fineness Modulus	2.19
4.	Type of Slag	Fine Coarse
5	Grading Zone	Nearly equal to sand
6	Water absorption	1.19%
7	Specific Gravity	3.58

**Table 3.7:** Sieve Analysis of Copper Slag

SIEVE SIZE	WT. Retained	WEIGHT RETAINED (CUMULATIVE)	PERCENTAGE RETAINED	PERCENTAGE PASSING
10mm	0.00	0	0.00	100.00
4.75mm	0.00	0	0.00	100.00
2.36mm	63.00	63	6.30	93.70
1.18mm	105.50	168.5	16.85	83.15
600mic	156.00	324.5	32.45	67.55
300mic	357.00	681.5	68.15	31.85
150mic	275.00	956.5	95.65	4.35
75mic	19.00	975.5	97.55	2.45
Pan	24.50	1000	100	

$\Sigma F = 219.00$

$$F M = \Sigma F / 100 = 2.19$$

### 3.2.5 Water

Water is an important constituent of concrete. In the present study, tap water was used for both casting and curing purposes.

### 3.3 Mix Proportion

Copper slag was used as partial replacement of 20, 40, 60 and 80% sand in manufacturing of dry lean concrete. A total of four mix combinations designated as N-100 (control concrete), S-CS-80-20 (80% natural Sand + 20% CS), S-CS-60-40 (60% natural Sand + 40% CS), S-CS-40-60 (40% Natural Sand + 60% CS), S-CS-20-80 (20% Natural Sand + 80% CS) all combinations are prepared in the laboratory. The slump test was performed and desired slump of 0 mm was achieved. Concrete mixture proportion are presented in Table 3.10. The different mix proportion was prepared by replacing sand with copper-slag.

The Sand replacement percentage is defined as the weight ratio of Copper Slag to the total Natural Sand in the concrete mixture and depending upon the selected replacement percentage, direct substitution of Natural Sand with an equal weight of Copper Slag particles is carried out

$$\text{Vol. of Fine Aggregate Replaced} = \frac{\% \text{age Replacement Wt. of Sand} \times 1000}{\text{Sp Gravity of Sand}} = \text{Vol. of C. Slag}$$

$$\text{Weight of Copper Slag} = \text{Vol. of Copper Slag} \times \text{sp. Gravity of CS} \times 1000$$

Calculation of fine aggregate and copper slag is on the basis of volumetric method.

For example -

$$\text{S-CS-80-20} = \text{VOL. OF FINE-AGGREGATE} = \text{WT. OF SAND} / \text{SP. GRAVITY OF SAND} \times 10^{-3}$$

$$945 / 2.65 \times 10^{-3} = 0.35566 \text{ cum } 0.35566 \times 80 / 100 = 0.28453$$

$$\text{VOL. OF COPPER SLAG (20\%)} = 0.07132, \text{ WEIGHT} = 0.07132 \times 3.58 \times 1000 = 255.33 \text{ kg/m}^3$$

The following weight combinations of N-100 and Copper Slag adopted are : N-100 (control mixture) & different perorations of S-CS. The concrete mixture proportions and the corresponding mix designations are presented in Table 3.10 and Table 3.11.

### 3.4 MIX DESIGN FOR DRY LEAN CONCRETE (DLC)

#### A. DESIGN PARAMETERS

1. TYPE OF CONCRETE : DRY LEAN CONCRETE
2. MINIMUM CEMENT CONTENT : 150 Kg/m<sup>3</sup> (Clause 601.30.3 of MORTH & H)
3. MAXIMUM SIZE OF AGGREGATE: 25 mm (Clause 601.3.1 of MORTH & H)
4. AGGREGATE CEMENT RATION : 15 : 1 (Clause 601.3.1 of MORTH & H)
5. GRADATION : AS PER TABLE 600.1 OF MORTH & H
6. STRENGTH REQUIRED AT 7 DAYS: 10 N/mm<sup>2</sup> (Clause 601.3.4 of MORTH & H)

#### B. MATERIAL SPECIFICATION

1. CEMENT : SHREE ULTRA OPC 43 GRADE
2. COURSE AGGREGATE : 20 & 10 mm as available
3. FINE SAND : PATHANKOT (as available)
4. SOURCE OF WATER : SIMPLE TAP WATER

#### C. PROPERTIES OF AGGREGATE

WATER ABSORPTION OF:-

20 MM Coarse aggregate :	0.39%
10 MM Coarse aggregate:	0.50%
SAND :	1.45%

#### D. DESIGN PARAMETERS

1. Cement : 150 Kg/m<sup>3</sup>
2. Coarse Aggregate 20mm : 720 Kg/m<sup>3</sup>
3. Coarse Aggregate 10mm : 585 Kg/m<sup>3</sup>
4. Fine Aggregate (Sand) : 945 Kg/m<sup>3</sup>

Table 3.8 shows in percentage mixing ratios of coarse aggregates (20mm & 10mm sizes) and fine aggregate.

**Table 3.8:** Mix proportions for Material

Material Mixed	20 mm Coarse Aggregate	10 mm Coarse Aggregate	Fine Aggregate
Percentage Mixed	38.00%	20.00%	42.00%

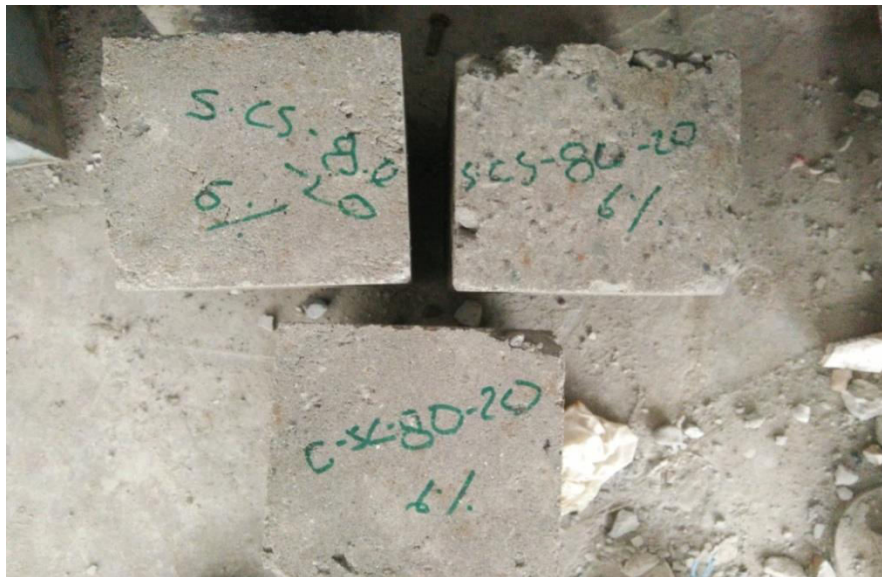
**Table 3.9:** Mix Proportions for Different Samples

Designation	Replacement(%)	Cement (kg/m <sup>3</sup> )	Coarse Aggregate (kg/m <sup>3</sup> (20mm))	Coarse Aggregate (kg/m <sup>3</sup> (10mm))	Total Coarse Aggregate (kg/m <sup>3</sup> )	Fine Aggregate (kg/m <sup>3</sup> )	Copper Slag (kg/m <sup>3</sup> )	Water (kg/m <sup>3</sup> )
Control Mix-N-100	-	150	783.00	522.00	1305.00	945.00	0.0	120.00
S-CS-80-20	20%	150	783.00	522.00	1305.00	756.00	255.33	120.00
S-CS-60-40	40%	150	783.00	522.00	1305.00	567.00	510.66	120.00
S-CS-40-60	60%	150	783.00	522.00	1305.00	378.00	765.98	120.00
S-CS-20-80	80%	150	783.00	522.00	1305.00	189.00	1021.31	120.00

Table 3.9 shows various proportions of mix, replacement of sand with copper slag. In table all other contents are same except fine aggregate, which is replaced by copper slag in various percentages.

### 3.5. Casting of Specimens

The procedure for casting of specimens for Density and Compressive strength test is discussed in this section. Cube specimens of dry lean concrete were cast for each percentage of moisture content i.e. 5.0%, 6.0% and 7.0% with various combinations of copper slag i.e 0%, 20%, 40%, 60%, and 80%. Six number of cube specimens were cast for each combination of copper slag with each percentage of moisture content. Six cube specimens of size 150×150×150mm were cast for static compressive test. The quantity of cement, coarse aggregate, fine aggregate, Copper Slag and water for each mix was weighed separately. The Sand and copper slag were dry mixed to attain a uniform mix separately. Cement is mixed into the blend in dry form. The coarse aggregates were mixed to get the same throughout the batch. Initially 50 to 70% of water was added to the mix and then mixed thoroughly for 3 to 4 minutes, remaining water then added to the mixture and mixed again. The compaction of concrete in moulds was carried out by using vibrating Table. After casting, the specimens were kept for 24 hours. Next day the specimen was take out from mould and the specimen are kept in curing tank. For each mix 6 cubes were cast i.e three cubes for each 7days and 28days compressive strength test. The cubes after casting are shown in Plate 3.3.



**Plate 3.2:** Plan of Cube Casted

### 3.6 Test method

#### 3.6.1 Compressive strength test

The specimens were tested for compressive strength at 7 days and 28 days as per BIS 516-1959. The compressive strength was calculated by dividing failure-load by average-sectional area. The average value of 3 samples was taken as the compressive strength of the batch.

The compressive strength test is carried out on ACTM machine from AIMIL and have a capacity of 5000 KN is used for determining the maximum loads carried by concrete cube specimen. The arrangement for compressive strength test is shown in Plate 3.3. At the age of test, the specimens were taken out of the curing tank and kept outside at room temperature for 10 – 15 minutes so it becomes surface dry. Then the specimen was tested for compressive by placing the cube specimen on the steel plate of the machine such that load axis is perpendicular to the casting position. Then cube specimen was loaded at the rate of 300 kN/minute as specified in IS: 516 - 1959. Maximum load at the failure of specimen was recorded as the failure load.



**Plate 3.3:** Testing of Cube for compressive strength

### 3.6.2 Density of Mixes

Density of Mixes recorded at the time of casting for different mixes are as given in tables below

**TABLE No. 3.10:** Density of - Control Mix

Sr.no.	Moisture content	Cube no	Vol. of cube (cc)	Wt. of empty cube mould	Wt.ofmould+conc.	Wt.of conc.	Wet density(g/cc)	Dry density(g/cc)
1	5.00%	1	3375.00	8.78	17.11	8.33	2.468	2.351
2		2	3375.00	9.02	17.25	8.23	2.439	2.322
3		3	3375.00	9.03	17.45	8.42	2.495	2.376
4		4	3375.00	8.80	17.12	8.32	2.465	2.465
5		5	3375.00	8.79	17.02	8.23	2.439	2.439
6		6	3375.00	8.80	17.12	8.32	2.465	2.465
1	6.00%	1	3375.00	8.91	17.35	8.44	2.500	2.360
2		2	3375.00	8.79	17.25	8.46	2.510	2.360
3		3	3375.00	9.01	17.43	8.42	2.490	2.350
4		4	3375.00	9.02	17.48	8.46	2.507	2.507
5		5	3375.00	9.02	17.47	8.45	2.504	2.504
6		6	3375.00	9.03	17.46	8.43	2.498	2.498
1	7.00%	1	3375.00	8.90	17.29	8.39	2.486	2.323
2		2	3375.00	9.03	17.44	8.41	2.492	2.329
3		3	3375.00	8.97	17.40	8.43	2.498	2.334
4		4	3375.00	9.02	17.44	8.42	2.490	2.490
5		5	3375.00	9.03	17.41	8.38	2.480	2.480
6		6	3375.00	9.02	17.41	8.39	2.490	2.490

**TABLE No. 3.11:** Density of Mix – S-CS-80-20

SR.NO.	MOISTURE CONTENT	CUBE NO	VOL. OF CUBE (CC)	WT. OF EMPTY CUBE MOULD	WT.OF MOULD+ CONC.	WT.OF CONC.	WET DENSITY (g/cc)	DRY DENSITY (g/cc)
1	5.00%	1	3375.00	8.78	17.31	8.53	2.527	2.407
2		2	3375.00	9.02	17.51	8.49	2.516	2.396
3		3	3375.00	9.03	17.54	8.51	2.521	2.401
4		4	3375.00	8.80	17.36	8.56	2.536	2.536

5		5	3375.00	8.79	17.32	8.53	2.527	2.527
6		6	3375.00	8.80	17.31	8.51	2.521	2.521
1	6.00%	1	3375.00	9.01	17.58	8.57	2.539	2.40
2		2	3375.00	8.79	17.34	8.55	2.533	2.39
3		3	3375.00	9.01	17.57	8.56	2.536	2.39
4		4	3375.00	8.97	17.53	8.56	2.536	2.536
5		5	3375.00	9.02	17.59	8.57	2.539	2.539
6		6	3375.00	9.01	17.57	8.56	2.536	2.536
1	7.00%	1	3375.00	8.98	17.53	8.55	2.533	2.368
2		2	3375.00	9.03	17.54	8.51	2.521	2.357
3		3	3375.00	8.97	17.53	8.56	2.536	2.370
4		4	3375.00	9.02	17.53	8.51	2.521	2.52
5		5	3375.00	9.03	17.56	8.53	2.527	2.53
6		6	3375.00	9.02	17.55	8.53	2.527	2.53

**TABLE No. 3.12:** Density of Mix – S-CS-60-40

SR.N O.	MOISTURE CONTENT	CUBE NO	VOL. OF CUBE (CC)	WT. OF EMPTY CUBE MOULD	WT.OF MOULD+ CONC.	WT.OF CONC.	WET DENSITY(g/cc )	DRY DENSITY(g/cc)
1	5.00%	1	3375.00	8.97	17.31	8.65	2.563	2.441
2		2	3375.00	9.02	17.51	8.65	2.563	2.441
3		3	3375.00	9.03	17.54	8.67	2.569	2.447
4		4	3375.00	8.80	17.36	8.66	2.566	2.566
5		5	3375.00	9.02	17.69	8.67	2.569	2.569
6		6	3375.00	8.80	17.48	8.68	2.572	2.572
1	6.00%	1	3375.00	8.88	17.58	8.70	2.578	2.43
2		2	3375.00	8.95	17.67	8.72	2.584	2.44
3		3	3375.00	9.01	17.75	8.74	2.590	2.44
4		4	3375.00	8.97	17.70	8.73	2.587	2.587
5		5	3375.00	9.02	17.76	8.74	2.590	2.590
6		6	3375.00	9.01	17.57	8.73	2.587	2.587
1	7.00%	1	3375.00	9.02	17.53	8.60	2.548	2.381
2		2	3375.00	9.03	17.54	8.63	2.557	2.390
3		3	3375.00	8.97	17.53	8.64	2.560	2.393
4		4	3375.00	8.97	17.53	8.67	2.569	2.57
5		5	3375.00	8.78	17.56	8.68	2.572	2.57
6		6	3375.00	9.05	17.55	8.67	2.569	2.57

**TABLE No. 3.13:** Density of Mix – S-CS-40-60

SR.NO.	MOISTURE CONTENT	CUBE NO	VOL. OF CUBE (CC)	WT. OF EMPTY CUBE MOULD	WT.OF MOULD +CONC.	WT. OF CONC.	WET DENSITY (g/cc)	DRY DENSITY (g/cc)
1	5.00%	1	3375.00	9.01	17.81	8.80	2.607	2.483
2		2	3375.00	8.97	17.75	8.78	2.601	2.478
3		3	3375.00	9.03	17.83	8.80	2.607	2.483
4		4	3375.00	9.01	17.82	8.81	2.610	2.610
5		5	3375.00	8.85	17.64	8.79	2.604	2.604
6		6	3375.00	8.80	17.60	8.80	2.607	2.607
1	6.00%	1	3375.00	8.97	17.73	8.76	2.596	2.45
2		2	3375.00	8.79	17.56	8.77	2.599	2.45
3		3	3375.00	9.01	17.76	8.75	2.593	2.45
4		4	3375.00	9.03	17.83	8.80	2.607	2.607
5		5	3375.00	9.02	17.78	8.76	2.596	2.596
6		6	3375.00	9.07	17.82	8.75	2.593	2.593
1	7.00%	1	3375.00	9.05	17.72	8.67	2.569	2.401
2		2	3375.00	9.03	17.69	8.66	2.566	2.398
3		3	3375.00	8.97	17.65	8.68	2.572	2.404
4		4	3375.00	8.98	17.65	8.67	2.569	2.57
5		5	3375.00	9.03	17.69	8.66	2.566	2.57
6		6	3375.00	8.87	17.52	8.65	2.563	2.56

**TABLE No. 3.14:** Density of Mix – S-CS-20-80

SR.NO.	MOISTURE CONTENT	CUBE NO	VOL. OF CUBE (CC)	WT. OF EMPTY CUBE MOULD	WT.OF MOULD+CONC.	WT.OF CONC.	WET DENSITY (g/cc)	DRY DENSITY (g/cc)
1	5.00%	1	3375.00	9.02	17.90	8.88	2.631	2.51
2		2	3375.00	8.97	17.87	8.90	2.637	2.51
3		3	3375.00	9.03	17.92	8.89	2.634	2.51
4		4	3375.00	8.95	17.82	8.87	2.628	2.63
5		5	3375.00	8.79	17.68	8.89	2.634	2.63
6		6	3375.00	9.05	17.95	8.90	2.637	2.64
1	6.00%	1	3375.00	9.01	17.82	8.81	2.610	2.46

2		2	3375.00	8.79	17.62	8.83	2.616	2.47
3		3	3375.00	9.01	17.86	8.85	2.622	2.47
4		4	3375.00	8.97	17.80	8.83	2.616	2.62
5		5	3375.00	9.05	17.89	8.84	2.619	2.62
6		6	3375.00	9.06	17.91	8.85	2.622	2.62
1		7.00%	1	3375.00	9.01	17.73	8.72	2.584
2	2		3375.00	9.03	17.76	8.73	2.587	2.42
3	3		3375.00	8.97	17.72	8.75	2.593	2.42
4	4		3375.00	9.02	17.75	8.73	2.587	2.59
5	5		3375.00	9.03	17.74	8.71	2.581	2.58
6	6		3375.00	9.02	17.75	8.73	2.587	2.59



**Plate 3.4:** Testing of Cube for compressive strength on ACTM

#### **4.1 General**

This chapter presents the results of compressive strength, and density of various concrete mix proportions. The effect of copper slag as partial replacement of sand in dry lean concrete was investigated by performing tests as per procedure described in Chapter 3. To analyze the strength characteristics the experimental/ measured strength of all the mix combinations at various water content compared and discussed.

#### **4.2. Density of Dry Lean Concrete (DLC)**

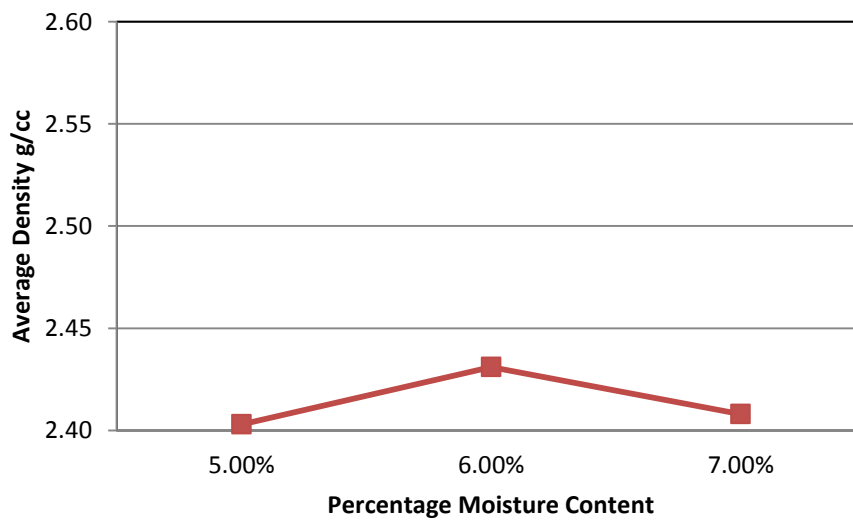
Density of cube specimens for all mix proportion at various water content prepared for 7 and 28 days are presented in Table 4.1 -4.5. Density is calculated at the time of casting. The data is further represented in the form of graphs in Figure 4.1 – 4.5.

- It is observed from Table No. 4.1, 4.3 and Figures 4.1, 4.3 the density is maximum at 6.0% of moisture content in control concrete mixture and concrete mixture containing 60% sand and 40% copper slag (S-CS-60-40).
- It is observed from Table No. 4.2 and Figure 4.2 the density is almost same & maximum at 5.0% and 6.0% of moisture content in S-CS-80-20, but decreases after 6.0% moisture content.
- It is observed this from Table No. 4.4, 4.5 and Figure 4.4, 4.5 the density is maximum at 5.0% of moisture content in further it is decreasing with increase of moisture content in the mix of S-CS-40-60 & S-CS-20-80.
- From all the combination it is observed that Density is maximum (2.571 g/cc) of the mix S-CS-20-80 at 5.0% moisture content from this we can say that density of mix increases with the increases of copper slag in the mix and it will use less moisture content. It is due to the density of copper slag is more than the density of sand and copper slag also has a less water absorption.

**TABLE No. 4.1:** Comparison of Density - Control Mix

Sr.No.	Moisture Content	Wet Density (g/cc)	Avg. Wet Density (g/cc)	Dry Density (g/cc)	Avg. Dry Density (g/cc)
1	5.00%	2.468	2.462	2.351	2.403
2		2.439		2.322	
3		2.495		2.376	
4		2.465		2.465	
5		2.439		2.439	
6		2.465		2.465	
1	6.00%	2.500	2.502	2.360	2.431
2		2.510		2.360	
3		2.490		2.350	
4		2.507		2.507	
5		2.504		2.504	
6		2.498		2.498	
1	7.00%	2.486	2.490	2.323	2.408
2		2.492		2.329	
3		2.498		2.334	
4		2.490		2.490	
5		2.480		2.480	
6		2.490		2.490	

**Moisture Content vs Density**



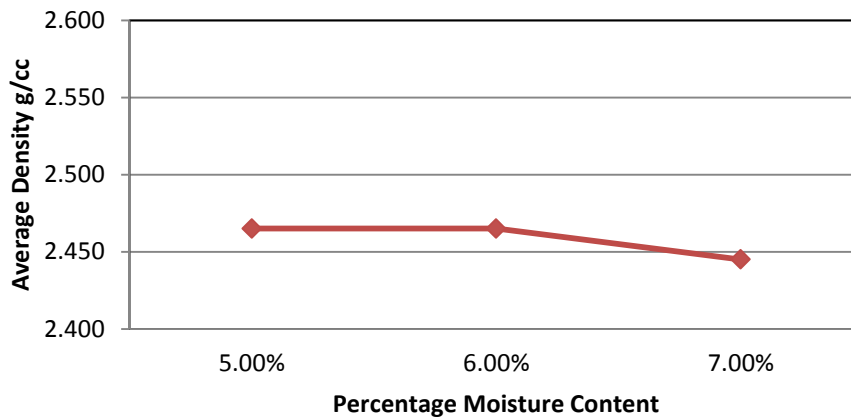
**FIGURE 4.1:**Comparison of Density - Control Mix

It is observed from Table No. 4.1 and Figures 4.1 that the density is maximum at 6.0% of moisture content in control concrete mixture and concrete mixture containing 60% sand and 40% copper slag (S-CS-60-40).

**TABLE No. 4.2:**Comparison of Density Mix – S-CS-80-20

Sr.No.	Moisture Content	Wet Density(g/cc)	Avg. Wet Density (g/cc)	Dry Density(g/cc)	Avg. Density (g/cc)
1	5.00%	2.527	2.525	2.407	2.465
2		2.516		2.396	
3		2.521		2.401	
4		2.536		2.536	
5		2.527		2.527	
6		2.521		2.521	
1	6.00%	2.539	2.537	2.40	2.465
2		2.533		2.39	
3		2.536		2.39	
4		2.536		2.536	
5		2.539		2.539	
6		2.536		2.536	
1	7.00%	2.533	2.528	2.368	2.445
2		2.521		2.357	
3		2.536		2.370	
4		2.521		2.52	
5		2.527		2.53	
6		2.527		2.53	

## Moisture Content vs Density

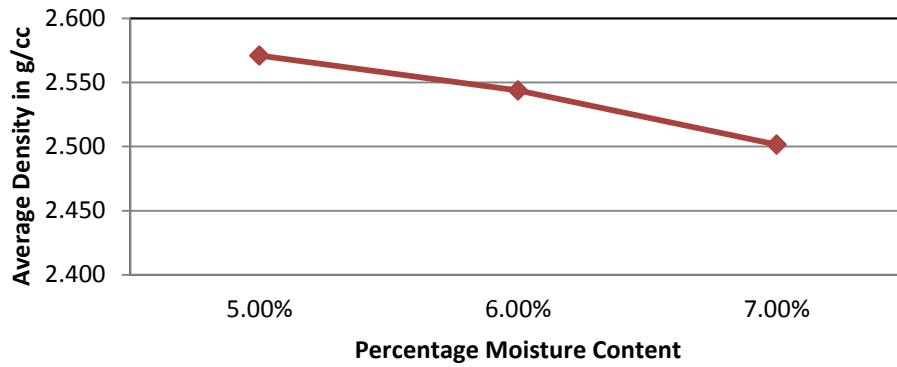


**FIGURE 4.2:** Comparison of Density Mix- S-CS-80-20

**TABLE No. 4.3:** Comparison of Density Mix – S-CS-60-40

Sr.No.	Moisture Content	Wet Density(g/cc)	Avg. Wet Density(g/cc)	Dry Density(g/cc)	Avg. Dry Density(g/cc)
1	5.00%	2.563	2.567	2.441	2.506
2		2.563		2.441	
3		2.569		2.447	
4		2.566		2.566	
5		2.569		2.569	
6		2.572		2.572	
1	6.00%	2.578	2.586	2.43	2.513
2		2.584		2.44	
3		2.590		2.44	
4		2.587		2.587	
5		2.590		2.590	
6		2.587		2.587	
1	7.00%	2.548	2.562	2.381	2.479
2		2.557		2.390	
3		2.560		2.393	
4		2.569		2.57	
5		2.572		2.57	
6		2.569		2.57	

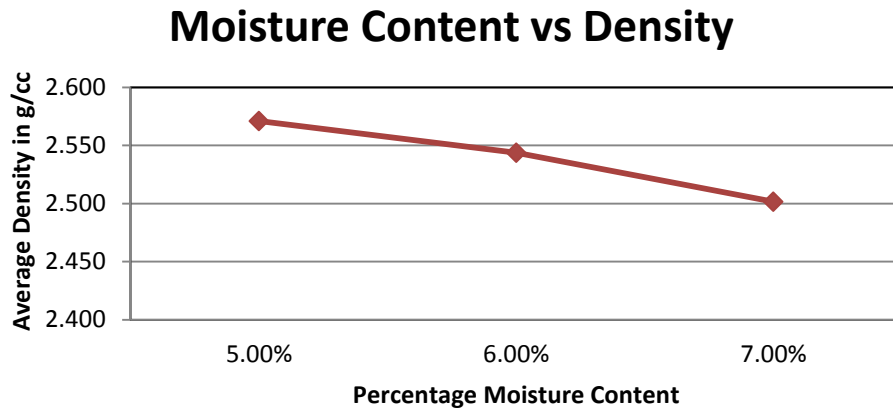
## Moisture Content vs Density



**FIGURE 4.3:** Comparison of Density Mix – S-CS-60-40

**TABLE No. 4.4:** Comparison of Density Mix – S-CS-40-60

Sr.No.	Moisture Content	Wet Density (g/cc)	Avg. Wet Density (g/cc)	Dry Density (g/cc)	Avg. Density (g/cc)
1	5.00%	2.607	2.606	2.483	2.544
2		2.601		2.478	
3		2.607		2.483	
4		2.610		2.610	
5		2.604		2.604	
6		2.607		2.607	
1	6.00%	2.596	2.597	2.45	2.524
2		2.599		2.45	
3		2.593		2.45	
4		2.607		2.607	
5		2.596		2.596	
6		2.593		2.593	
1	7.00%	2.569	2.567	2.401	2.483
2		2.566		2.398	
3		2.572		2.404	
4		2.569		2.57	
5		2.566		2.57	
6		2.563		2.56	



**FIGURE 4.4** Comparison of Density Mix – S-CS-40-60

**TABLE No. 4.5:** Comparison of Density Mix- S-CS-20-80

Sr.No.	Moisture Content	Wet Density (g/cc)	Avg. Wet Density (g/cc)	Dry Density (g/cc)	Avg. Dry Density (g/cc)
1	5.00%	2.631	2.634	2.506	2.571
2		2.637		2.511	
3		2.634		2.509	
4		2.628		2.628	
5		2.634		2.634	
6		2.637		2.637	
1	6.00%	2.610	2.618	2.46	2.544
2		2.616		2.47	
3		2.622		2.47	
4		2.616		2.616	
5		2.619		2.619	
6		2.622		2.622	
1	7.00%	2.584	2.586	2.415	2.502
2		2.587		2.417	
3		2.593		2.423	
4		2.587		2.59	
5		2.581		2.58	
6		2.587		2.59	

### Moisture Content vs Density

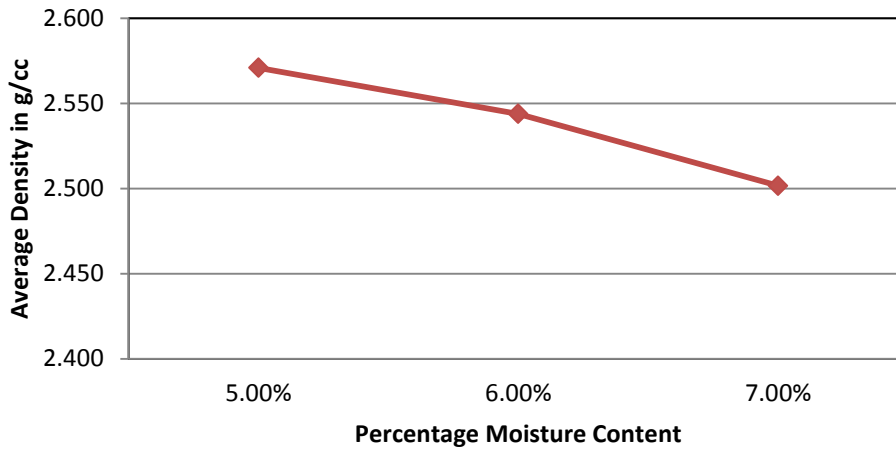


FIGURE 4.5 Comparison of Density Mix – S-CS-20-80

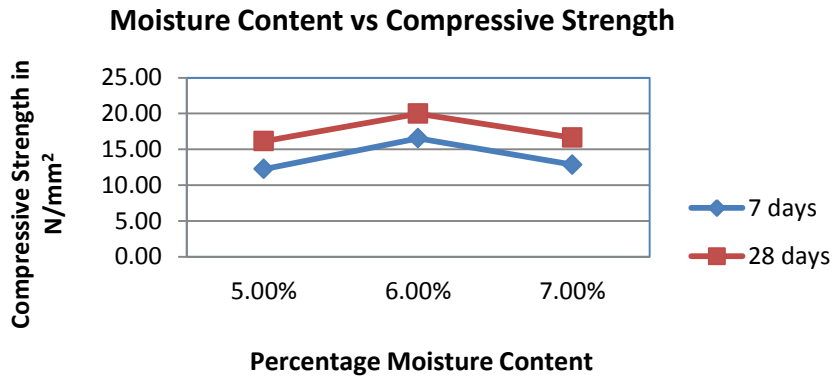
#### 4.3. Compressive Strength of DLC with various Moisture Content and Copper Slag Mixes

Compressive Strength of cube specimens for all mix proportion at various water content prepared for 7 and 28 days are presented in Table 4.6 – 4.10. Compressive Strength of all the cubes tested at different ages as described in the chapter 3<sup>rd</sup>. The data is further represented in the form of graphs in Figure 4.6 – 4.10

TABLE NO. 4.6: Comparison of Compressive Strength of DLCCubes Control Mix N-100 After 7 and 28 days

SR. No	MOISTURE CONTENT	AGE OF CUBE (DAYS)	DENSITY OF CUBE g/cm <sup>3</sup>	LOAD (kN)	STRENGTH (N/mm <sup>2</sup> )	AVERAGE STRENGTH (N/mm <sup>2</sup> )
1	5.00%	7	2.468	276.00	12.27	12.26
2			2.439	275.50	12.24	
3			2.495	276.00	12.27	
4		28	2.465	363.00	16.13	16.13
5			2.439	364.50	16.20	
6			2.465	361.50	16.07	
1	6.00%	7	2.501	374.50	16.64	16.53
2			2.507	371.80	16.52	
3			2.495	369.80	16.44	
4		28	2.507	451.50	20.07	20.00
5			2.504	448.60	19.94	
6			2.498	449.70	19.99	

1	7.00%	7	2.486	286.00	12.71	12.86
2			2.492	298.50	13.27	
3			2.498	283.40	12.60	
4		28	2.495	379.00	16.84	16.64
5			2.483	375.50	16.69	
6			2.486	368.50	16.38	

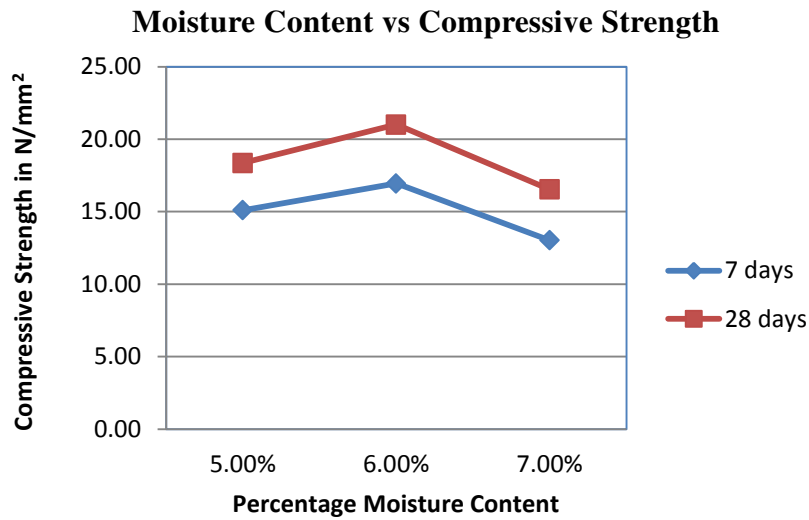


**FIGURE 4.6:** Comparison of Compressive Strength of DLCCubes Control Mix N-100 After 7 and 28 days

**TABLE NO. 4.7:** Comparison of Compressive Strength of DLC Cubes S-CS-80-20 After 7 and 28 days

SR. No	MOISTURE CONTENT	AGE OF CUBE (DAYS)	DENSITY OF CUBE (g/cm <sup>3</sup> )	LOAD (kN)	STRENGTH	AVERAGE STRENGTH
1	5.00%	7	2.527	341.00	15.16	15.10
2			2.516	345.60	15.36	
3			2.521	332.50	14.78	
4		28	2.536	408.70	18.16	18.36
5			2.527	418.00	18.58	
6			2.521	412.50	18.33	
1	6.00%	7	2.539	387.50	17.22	16.94
2			2.533	376.00	16.71	
3			2.536	380.00	16.89	
4		28	2.536	473.00	21.02	21.01
5			2.539	477.50	21.22	
6			2.536	468.00	20.80	
1	7.00%	7	2.533	295.80	13.15	13.03
2			2.521	300.50	13.36	
3			2.536	283.40	12.60	
4		28	2.521	370.50	16.47	16.54

5			2.527	376.00	16.71	
6			2.527	369.80	16.44	

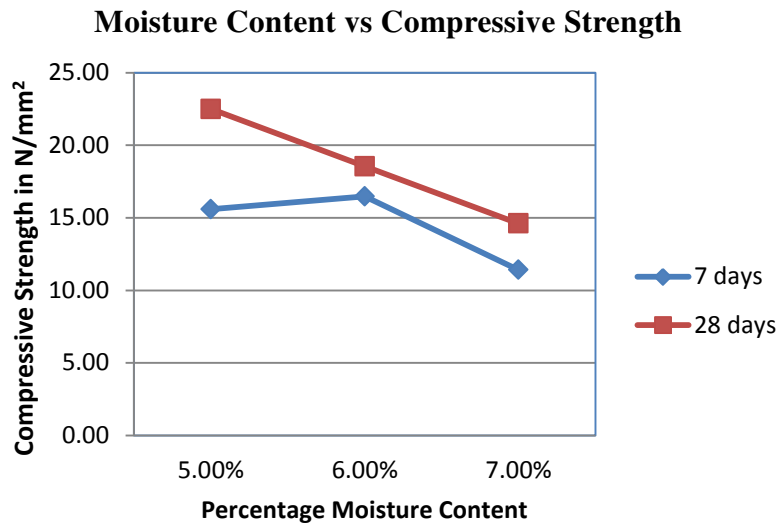


**FIGURE 4.7:** Comparison of Compressive Strength of DLC Cubes S-CS-80-20 After 7 and 28 days

**TABLE NO. 4.8:** Comparison of Compressive Strength of DLC Cubes S-CS-60-40 After 7 and 28 days

SR. No	MOISTURE CONTENT	AGE OF CUBE (DAYS)	DENSITY OF CUBE g/cm <sup>3</sup>	LOAD (kN)	STRENGTH	AVERAGE STRENGTH
1	5.00%	7	2.563	342.60	15.23	15.59
2			2.563	357.00	15.87	
3			2.569	353.00	15.69	
4		28	2.566	502.40	22.33	22.49
5			2.569	517.00	22.98	
6			2.572	498.60	22.16	
1	6.00%	7	2.578	379.80	16.88	16.47
2			2.584	362.50	16.11	
3			2.590	369.70	16.43	
4		28	2.587	413.00	18.36	18.55
5			2.590	421.50	18.73	
6			2.587	417.80	18.57	
1	7.00%	7	2.548	253.00	11.24	11.41
2			2.557	261.50	11.62	
3			2.560	256.00	11.38	
4		28	2.569	324.00	14.40	14.61
5			2.572	334.60	14.87	

6			2.569	327.50	14.56	
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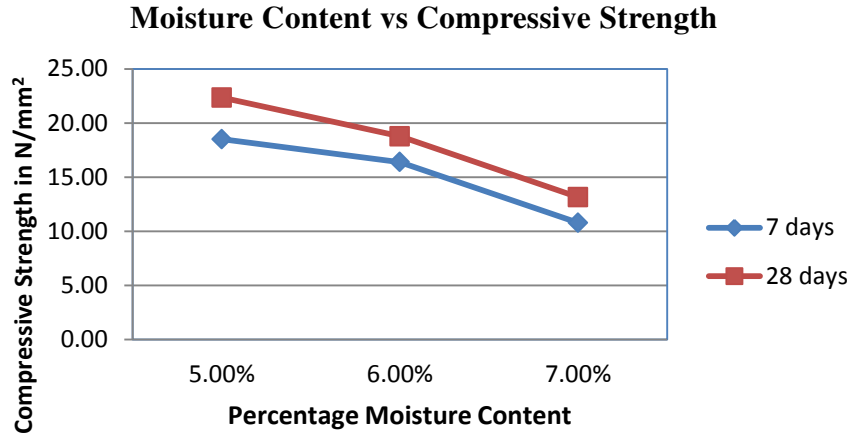


**FIGURE 4.8:** Comparison of Compressive Strength of DLC Cubes S-CS-60-40 After 7 and 28 days

**TABLE NO. 4.9:** Comparison of Compressive Strength of DLC Cubes S-CS-40-60 After 7 and 28 days

SR. No	MOISTURE CONTENT	AGE OF CUBE (DAYS)	DENSITY OF CUBE g/cm <sup>3</sup>	LOAD (kN)	STRENGTH	AVERAGE STRENGTH
1	5.00%	7	2.607	425.80	18.92	18.50
2			2.601	408.00	18.13	
3			2.607	415.00	18.44	
4		28	2.610	511.20	22.72	22.35
5			2.604	495.80	22.04	
6			2.607	501.50	22.29	
1	6.00%	7	2.596	375.00	16.67	16.39
2			2.599	364.00	16.18	
3			2.593	367.50	16.33	
4		28	2.607	415.00	18.44	18.77
5			2.596	427.50	19.00	
6			2.593	424.50	18.87	
1	7.00%	7	2.569	246.70	10.96	10.79
2			2.566	238.50	10.60	
3			2.572	243.00	10.80	

4			2.569	289.00	12.84	13.16
5			2.566	298.00	13.24	
6		28	2.563	301.50	13.40	

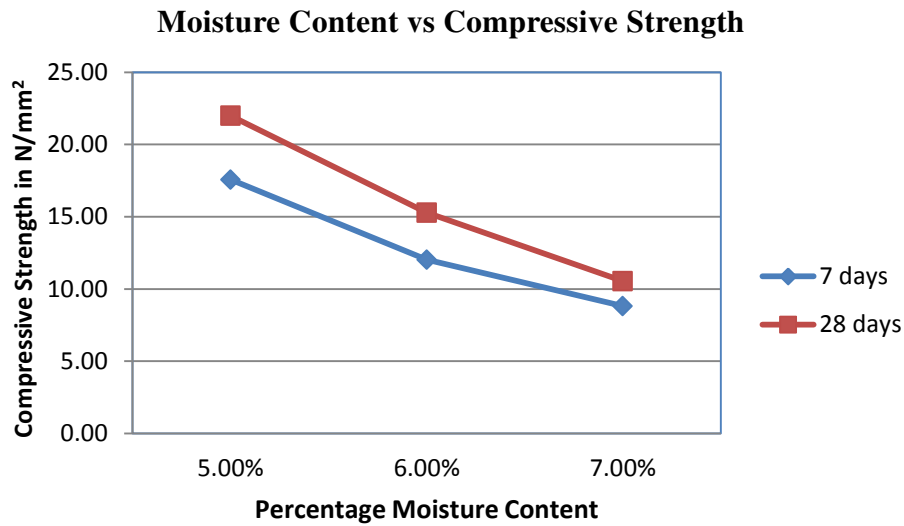


**FIGURE 4.9:** Comparison of Compressive Strength of DLC Cubes S-CS-40-60 After 7 and 28 days

**TABLE NO. 4.10:** Comparison of Compressive Strength of DLC Cubes S-CS-20-80 After 7 and 28 days

SR. No	MOISTURE CONTENT	AGE OF CUBE (DAYS)	DENSITY OF CUBE (g/cm <sup>3</sup> )	LOAD (kN)	STRENGTH	AVERAGE STRENGTH
1	5.00%	7	2.631	401.50	17.84	17.56
2			2.637	393.60	17.49	
3			2.634	390.00	17.33	
4		28	2.628	504.50	22.42	21.98
5			2.634	487.50	21.67	
6			2.637	491.60	21.85	
1	6.00%	7	2.610	271.50	12.07	12.02
2			2.616	269.00	11.96	
3			2.622	271.00	12.04	
4		28	2.616	345.00	15.33	15.28
5			2.619	347.50	15.44	
6			2.622	338.90	15.06	
1	7.00%	7	2.584	201.50	8.96	8.81
2			2.587	198.50	8.82	
3			2.593	195.00	8.67	
4		28	2.587	240.50	10.69	10.54

5			2.581	238.00	10.58	
6			2.587	232.80	10.35	



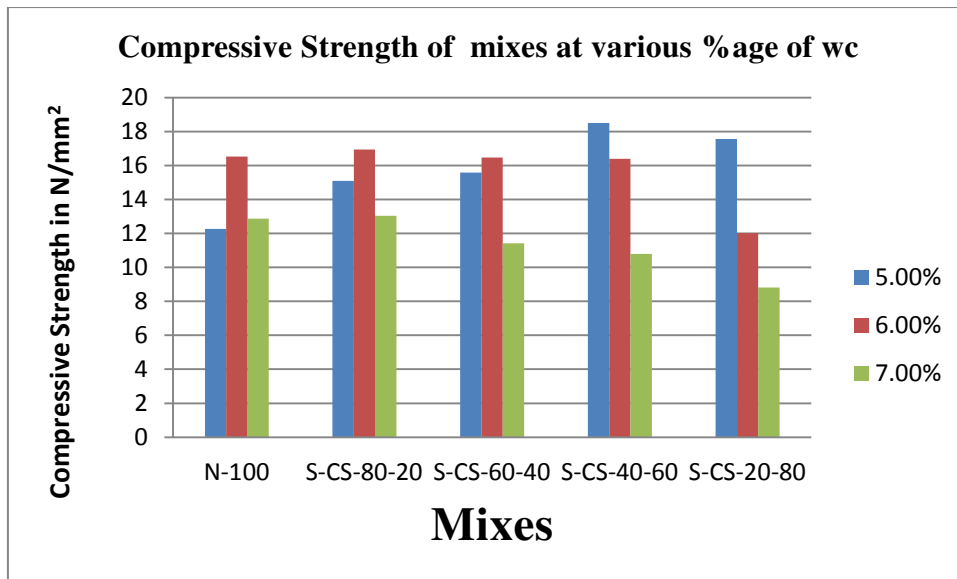
**FIGURE 4.10:** Comparison of Compressive Strength of DLC Cubes S-CS-20-80 After 7 and 28 days

#### 4.4 Comparison of Compressive Strength of Mixes

##### 4.4.1 Compressive Strengths at 7 days

**TABLE NO. 4.11:** Comparison of Compressive Strength of Mixes At 7-DAYS

SR. No	MOISTURE CONTENT	Compressive strength after 7 days				
		N-100	S-CS-80-20	S-CS-60-40	S-CS-40-60	S-CS-20-80
1	5.00%	12.26	15.1	15.59	18.50	17.56
2	6.00%	16.53	16.94	16.47	16.39	12.02
3	7.00%	12.86	13.03	11.41	10.79	8.81



**FIGURE 4.11:** Comparison of Compressive Strength of Mixes At 7-DAYS

From the Table 4.11 it is observed that in control mix (N-100) has maximum compressive strength ( $16.53 \text{ N/mm}^2$ ) at 6% of moisture content, but overall maximum value  $18.50 \text{ N/mm}^2$  in the mix (S-CS-40-60) where 40% Fine Aggregate and 60% of Copper Slag and further  $17.56 \text{ N/mm}^2$  in mix (S-CS-20-80) where 20% Fine Aggregate and 80% of Copper Slag at the 5% moisture content. It means If we have more wastage of slag, we can save sand by replacing it maximum 80% with Copper Slag. Although 60% or 80% replacement of fine aggregate giving slightly less compressive strength, but it is more than control mix.

#### 4.4.2 Compressive Strengths at 28 days

**TABLE NO. 4.12:** Comparison of Compressive Strength of Mixes At 28-Days

Sr. No	Moisture Content	Compressive Strength After 28 Days				
		N-100	S-CS-80-20	S-CS-60-40	S-CS-40-60	S-CS-20-80
1	5.00%	16.13	18.36	22.49	22.35	21.98
2	6.00%	20.00	21.01	18.55	18.77	15.28

3	7.00%	16.64	16.54	14.61	13.16	10.54
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Table 4.12 shows that Compressive Strength of 28 days maximum (22.49 N/mm<sup>2</sup>) is given by the mix (S-CS-60-40) where 60% Fine Aggregate and 40% of Copper Slag at 5.0% moisture content. Compressive strength (22.35 N/mm<sup>2</sup>) of the combination (S-CS-40-60) where 40% fine aggregate & 60% Copper slag is also very near to the maximum strength at the same moisture content. Further it also minor decrease in strength (21.98 N/mm<sup>2</sup>) in combination (S-CS-20-80) where 20% fine aggregate & 80% copper slag. If we have more wastage of copper slag, we can save fine aggregates by replacing it with maximum 80%. Although 80% or 60% replacement of fine aggregate giving slightly less compressive strength, but it is still higher as compare to than control mix.

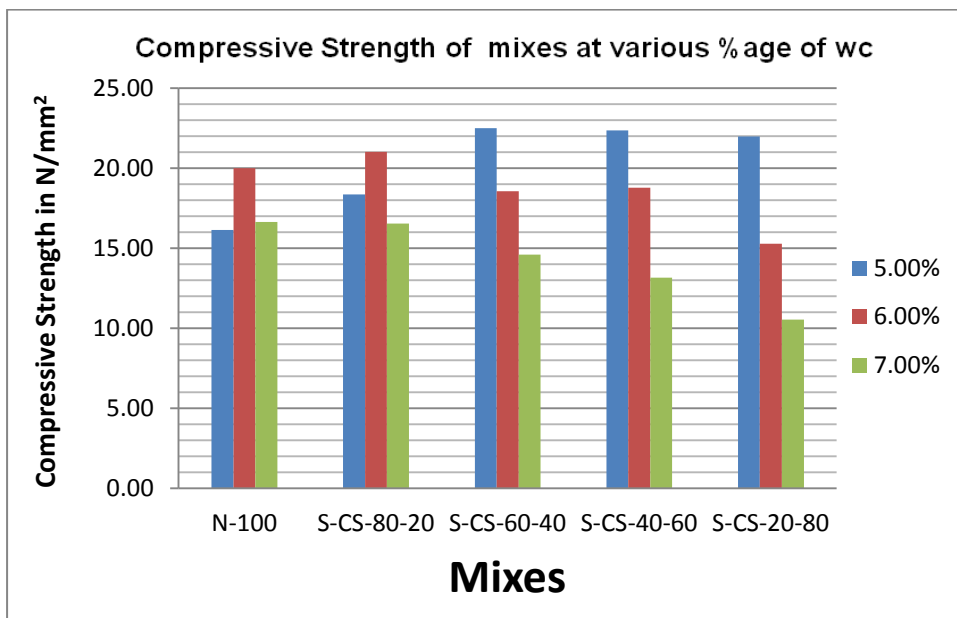


FIGURE 4.12: Comparison of Compressive Strength of Mixes At 28-Days

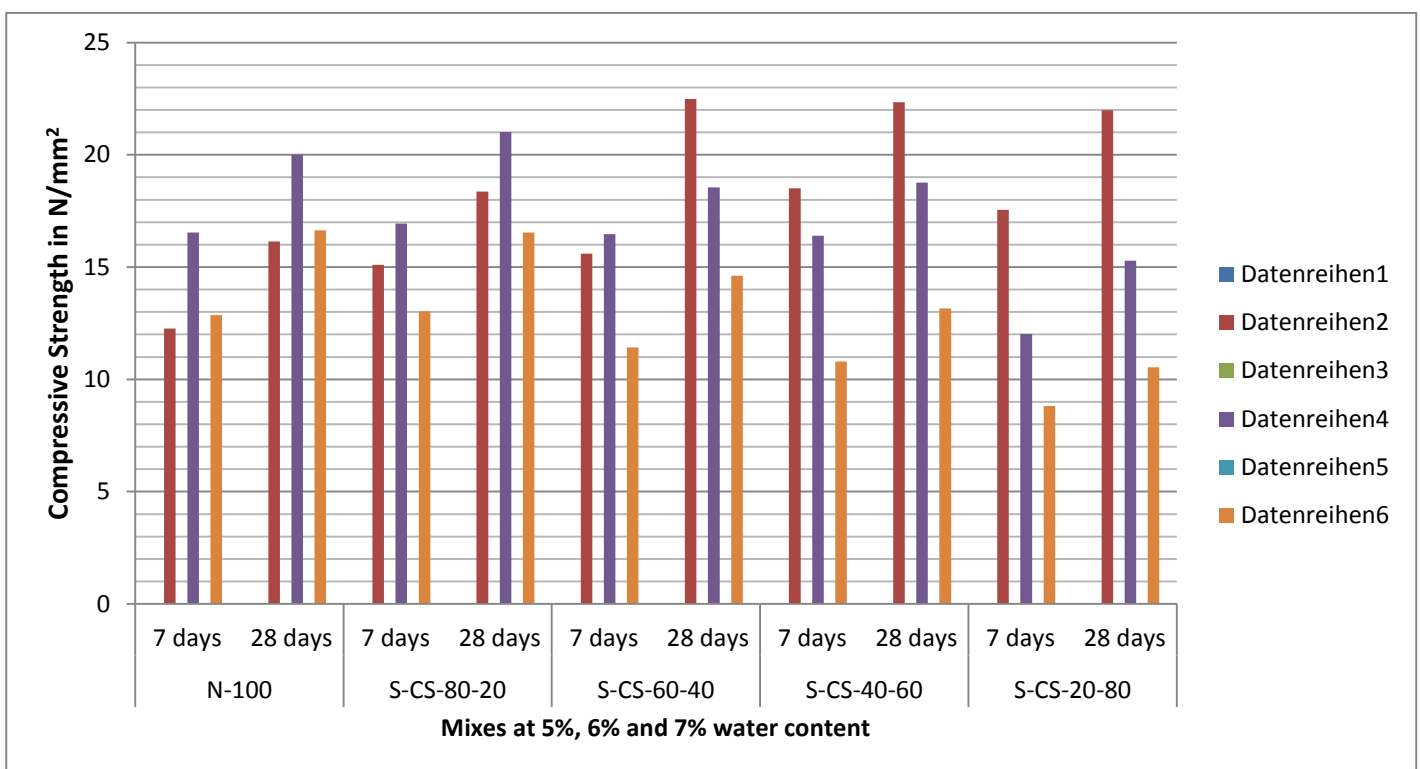
#### 4.4.3 Comparison of Compressive Strengths of All Mixes at 7 and 28 days

TABLE NO. 4.13: Comparison of Compressive Strength of All The Mixes At 7 & 28 Days

		COMPRESSIVE STRENGTH OF ALL MIXES									
SR. No	MOISTURE CONTENT	CONTROL MIX N-100		S-CS-80-20		S-CS-60-40		S-CS-40-60		S-CS-20-80	
		7 days	28 days	7 days	28 days	7 days	28 days	7 days	28 days	7 days	28 days

1	5.00%	12.26	16.13	15.10	18.36	15.59	22.49	18.50	22.35	17.56	21.98
2	6.00%	16.53	20.00	16.94	21.01	16.47	18.55	16.39	18.77	12.02	15.28
3	7.00%	12.86	16.64	13.03	16.54	11.41	14.61	10.79	13.16	8.81	10.54

From above combination it is observed that Compressive Strength of 7 days maximum (18.50 N/mm<sup>2</sup>) is given by the combination(S-CS-40-60) where 40% Fine Aggregate and 60% Copper Slag and 28days maximum(22.49 N/mm<sup>2</sup>) is given by the mix (S-CS-60-40)where 60% Fine Aggregate and 40% of Copper Slag at 5.0% moisture content.



**FIGURE 4.13:** Comparison of Compressive Strength of Mixes At 7 & 28 Days

Compressive Strength of cube specimens for all mix proportion at various water content prepared for 7 and 28days are presented in Table 4.6 -4.10 Compressive Strength is calculated at the 7days and 28days after casting. The data is further represented in the form of graphs in Figure 4.6 – 4.10.

- It is observed this from Table No. 4.6, 4.7 and Figure 4.6,4.7 ,the Compressive Strength of 7days & 28days is maximum at 6.0% of moisture content in control mix(N-100) and Mix (S-CS-80-20)where 80% Fine Aggregate and 20% Copper Slag.

- From Table No. 4.8, 4.9 & 4.10 and Figure 4.8, 4.9 & 4.10 it is observed that the Compressive Strength is more at 5.0% of moisture content in Mixes S-CS-60-40, S-CS-40-60 & S-CS-20-80.
- It is observed from Table No. 4.11 and Figure 4.11 that 7 days compressive strength ( $18.50 \text{ N/mm}^2$ ) is maximum at 5.0% of moisture content in the mix of S-CS-40-60.
- It is observed from Table No. 4.12 and Figure 4.12 that 28 days compressive strength ( $22.49 \text{ N/mm}^2$ ) is maximum at 5.0% of moisture content in the mix of S-CS-60-40.
- From all the combination it is observed that Compressive Strength of 28 days is maximum ( $22.49 \text{ N/mm}^2$ ) of the mix S-CS-60-40 at 5.0% moisture content.
- From all combination we concluded that although 28 days compressive strength is maximum in the Mix S-CS-60-40 but compressive strength (28 days) of Mixes S-CS-40-60 & S-CS-20-80 are also very near to the maximum strength  $22.35 \text{ N/mm}^2$  and  $21.98 \text{ N/mm}^2$  respectively at the same moisture content.
- So it is concluded & recommended that Mix S-CS-60-40 is the most efficient Mix in all the mixes and we can also use Mix S-CS-20-80 with some lack of strength in Dry Lean Concrete.

## CHAPTER 5

### CONCLUSIONS

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#### 5.1 General

The utilization of copper slag as partial replacement of sand in manufacturing of Dry lean Concrete was explored in the present study. Copper slag was used at 20, 40, 60 and 80%

replacement levels in dry lean concrete. The effect of copper slag on Density and Compressive strength of dry lean concrete was investigated. From the test results of dry lean concrete incorporating copper slag as partial slag, following conclusions have been drawn.

## 5.2 Conclusions

- It is observed that the density is maximum at 6.0% of moisture content in Control Mix (N-100) and Mix (S-CS-60-40) where 60% Fine Aggregate and 40% Copper Slag.
- It is observed that the density is almost same & maximum at 5.0% and 6.0% of moisture content in S-CS-80-20, but decreases at 7.0% moisture content.
- It is observed that the density is maximum at 5.0% of moisture content in further it is decreasing with increase of moisture content in the mix of (S-CS-40-60) where 40% Fine Aggregate and 60% Copper Slag & (S-CS-20-80) where 20% Fine Aggregate and 80% Copper Slag.
- From all the combination it is observed that Density is maximum (2.571 g/cc) of the mix (S-CS-20-80) where 20% Fine Aggregate and 80% Copper Slag at 5.0% moisture content from this we can say that density of mix increases with the increases of copper slag in the mix and it uses less moisture content. It is due to the density of copper slag is more than the densities of sand and copper slag also having a less water absorption.
- The use of up to 40% copper slag as fine aggregate in DLC increased its compressive strength. Further increases in the amount of copper slag resulted in the separation of cement paste from the mix and reduced the strength of the concrete.
- The copper slag used in the study was finer than the normally used fine aggregate and lacked the required amount of particles coarser than 600 micron. Therefore, it was essential to blend the slag with some suitable coarser material like iron slag before it could be used as a fine aggregate in concrete. The proportion of the blend will depend on the grading of copper slag as well as other constituents of fine aggregate.
- It is recommended that copper slag can be used in DLC mixes as a partial replacement of fine aggregate up to the level of 40%.
- It is observed that the Compressive Strength of 7 days & 28 days is maximum at 6.0% of moisture content in control mix and Mix S-CS-80-20.
- From Table No. 4.8, 4.9 & 4.10 and Figure 4.8, 4.9 & 4.10 it is observed that the Compressive Strength is more at 5.0% of moisture content in Mixes S-CS-60-40, S-CS-40-60 & S-CS-20-80.

- It is observed that 7 days compressive strength ( $18.50 \text{ N/mm}^2$ ) is maximum at 5.0% of moisture content in the mix of (S-CS-40-60) where 40% Fine Aggregate and 60% Copper Slag.
- It is observed that 28 days compressive strength ( $22.49 \text{ N/mm}^2$ ) is maximum at 5.0% of moisture content in the mix of S-CS-60-40 where 60% Fine Aggregate and 40% Copper Slag.
- From all the combination it is observed that Compressive Strength of 28 days is maximum ( $22.49 \text{ N/mm}^2$ ) of the mix S-CS-60-40 at 5.0% moisture content.
- From all combination we concluded that although 28 days compressive strength is Maximum in the Mix S-CS-60-40 but compressive strength (28 days) of Mixes S-CS-40-60 & S-CS-20-80 are also very near to the maximum strength  $22.35 \text{ N/mm}^2$  and  $21.98 \text{ N/mm}^2$  respectively at the same moisture content.
- So it is concluded & recommended that Mix S-CS-60-40 is the most efficient Mix among all mixes and we can also use Mix S-CS-20-80 with some lack of strength in Dry Lean Concrete.

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