

**EFFECT OF MARBLE DUST & FURNACE SLAG AS SAND
REPLACEMENT MATERIALS ON STRENGTH PROPERTIES OF
PAVEMENT QUALITY CONCRETE (PQC)**

A dissertation submitted
in partial fulfillment of the requirements for
the award of the degree of

**MASTER OF ENGINEERING
IN
STRUCTURAL ENGINEERING**

Submitted by:
**YOGESH KUMAR THAKUR
(ROLL NO. 801222023)**

UNDER THE GUIDANCE OF:

MANEEK KUMAR
Professor
Civil Engineering
Thapar University, Patiala

TANUJ CHOPRA
Assistant Professor
Civil Engineering
Thapar University, Patiala



**DEPARTMENT OF CIVIL ENGINEERING
THAPAR UNIVERSITY, PATIALA 147004**

JULY 2014

DECLARATION

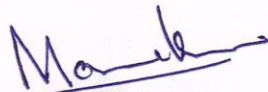
The author hereby declare that this dissertation entitled "*Effect of marble dust & furnace slag as sand replacement materials on strength properties of Pavement Quality Concrete (PQC)*", in whole or part has not been used to obtain any degree in this, or any other, institute, except where references have been given in text, it is entirely the author own work. The author conform that the library may lend or copy this upon request for academic purposes.



(YOGESH KUMAR THAKUR)
REGD.NO. 801222023

CERTIFICATE

This is to certify that the work presented in dissertation entitled "*Effect of marble dust & furnace slag as sand replacement materials on strength properties of Pavement Quality Concrete (PQC)*" submitted by **Mr. Yogesh Kumar Thakur** in partial fulfillment of the requirements for the award of degree of **Master of Engineering** in Structural Engineering at **Thapar University, Patiala**, is a bonafide work carried out by the student under our supervision and guidance. The matter embodied in this report has not been submitted anywhere for award of any other degree.



Dr. MANEEK KUMAR
Professor
Department of civil engineering
Thapar University, Patiala




Mr. TANUJ CHOPRA
Assistant Professor
Department of civil engineering
Thapar University, Patiala

COUNTERSIGNED



Dr. NAVEEN KWATRA
Chairman, Board of studies
Department of civil engineering
Thapar University, Patiala



Dr. S.K. MOHAPATRA
Dean, Academic Affairs
Thapar University, Patiala

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.

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. The cheerful support of my friends Ashish Awasti, Vinayak Kashyap, Akshay, Vicky, Amit, Rohit is sincerely appreciated for helping me in casting, curing and testing of specimens in the laboratory.

I am also thankful to all the staff members of Civil Engineering Department for their full cooperation and help.

Above all, I thank my parents and my elder brother, whose love and affectionate blessing have been a constant source of inspiration in making this manuscript a reality. 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.

(Yogesh Kumar Thakur)

INDEX

CERTIFICATE	[i]
ACKNOWLEDGEMENT	[ii]
ABSTRACT	[v]
LIST OF TABLES	[vi]
LIST OF FIGURES	[vii]
CHAPTER - 1 INTRODUCTION	
1.1 IMPACT OF MODERN CONCRETE	1
1.2 INTRODUCTION TO CONCRETE PAVEMENTS	1
1.1.1 Components of Concrete Pavement	2
1.2.2 Joints in Concrete Pavement	11
1.3 MARBLE DUST	13
1.3.1 Use of marble dust as replacement material in concrete	13
1.3.2 Chemical composition of marble dust	14
1.3.3 Physical properties of marble dust	14
1.4 BLAST FURNACE SLAG	14
1.4.1 Production of Blast furnace slag	14
1.4.2 Properties of Blast furnace slag	15
1.4.3 The Use of BF slag in road construction	16
1.3.4 Problems arrived from the Use of BF slag in road Construction	17
1.5 SCOPE OF PRESENT WORK	17
CHAPTER - 2 LITERATURE REVIEW	
2.0 GENERAL	18
2.1 USE OF MARBLE DUST IN CONCRETE	18
2.2 USE OF FURNACE SLAG IN CONCRETE	22
2.3 EFFECT OF SUPER PLASTICIZER ON CONCRETE PROPERITES	26
CHAPTER 3 MATERIALS TESTING AND EXPERIMENTAL PROGRAM	
3.1 GENERAL	29
3.2 MATERIAL USED	29
3.2.1 Portland Cement	
3.2.2 Aggregate	
3.2.3 Marble dust	
3.2.4 Furnace Slag	

	3.2.5 Water	
	3.2.6 Super plasticizer	
	3.3 MIX DESIGN OF PAVEMENT QUALITY CONCRETE (PQC)	37
	3.3.1 Design Parameters	37
	3.3.2 Step involves in the mix design as per IRC 44	38
	3.5 MAKING AND CURING OF TEST SPECIMENS IN LABORATORY	40
CHAPTER 4	RESULT AND DISCUSSION	
	4.1 GENERAL	41
	4.1 COMPRESSIVE STRENGTH OF CONCRETE	41
	4.2.1 General	41
	4.2.2 Test procedure and results for compressive strength	41
	4.2.3 Discussion of results	46
	4.2 FLEXURAL STRENGTH OF CONCRETE	50
	4.2.1 General	50
	4.3.2 Test procedure and results for flexural strength	50
	4.3.3 Discussion of results	55
CHAPTER 5	CONCLUSION	
	5.1 GENERAL	59
	5.2 COMPRESSIVE STRENGTH OF PAVEMENT QUALITY CONCRETE	59
	5.3 FLEXURAL STRENGTH OF PAVEMENT QUALITY CONCRETE	60
	5.4 SCOPE FOR FURTHER WORK	64
REFERENCES		62
ANNEXURE - 1	DESIGN OF PAVEMENT QUALITY CONCRETE SLAB AS PER IRC GUIDELINES	65

ABSTRACT

The demand for utilization of industrial by-products and wastes in road pavements is increasing and becoming more important. Government policies and public awareness is also contributing to the enhancement of both this demand and utilization. Various slags such as blast furnace and steel slag have been widely used in road pavements. On the other hand, marble dust creates large scale environmental pollution. Therefore, it could be possible to prevent the environmental pollution and to consume fewer natural resources as well through its utilization in increasing demand for road construction.

The present study aims at, developing pavement quality concrete mixtures incorporating marble dust and furnace slag as a partial fine aggregate replacement material. In this study the effect of marble dust & furnace slag on strength properties of Pavement Quality Concrete (PQC) are reported and the effect on the slab thickness of PQC pavement for the achieved flexural strength of the concrete mixtures incorporating marble dust and furnace slag has also been studied.

The study shows that the marble dust can be effectively replace sand up to 15% and furnace slag can be used up to 20% as replacement of sand in PQC. The maximum flexural strength is achieved for the mix containing 10% marble dust and 10% furnace slag as partial replacements of sand. The flexural strength increase is significant for mixes containing marble dust and furnace slag, with a combination up to certain limits of 25 to 30% in development of pavement quality concrete. This not only fulfills the IRC specification of PQC but also saves the other material ingredients used in concrete leading to economic design of the concrete slab for the pavement.

LIST OF TABLES

Table No.	Title
1.1	Type of Cement
1.2	Fine aggregates (IS 383-1970)
1.3	Aggregate Gradations for Dry Lean Concrete
1.4	Chemical composition of marble dust (Bahar Demirel, 2010)
1.6	Typical chemical properties of blast-furnace slag (<i>National Slag Association, 1985</i>)
3.1	Properties of OPC 43 Grade cement
3.2	Properties of Coarse Aggregates
3.3	Sieve Analysis of Coarse Aggregate (20mm)
3.4	Sieve Analysis of Coarse Aggregate (10mm)
3.5	Sieve Analysis of Fine Aggregate
3.6	Sieve Analysis of marble dust
3.7	Sieve Analysis of furnace slag
3.8	Properties of super plasticizer
3.9	Proportion for Pavement Quality Concrete Mixture (control mix)
3.10	Quantity of Material in kg/m ³ for different Mixes
4.1	Compressive Strength Test Result
4.2	Flexure Strength Test Results
6.1	Saving in concrete pavement thickness (mm)
6.2	Saving in materials in concrete with the use of marble dust and furnace slag

LIST OF FIGURES

Figure no.	Title
1.1	Pavement Dry Lean Concrete
1.2	Pavement Quality Concrete
1.3a	Dowel bar used in a contraction joint (D.V. Bhavanna Rao)
1.3b	Tie roads are used for longitudinal (D.V. Bhavanna Rao)
1.4	Production of blast furnace & steel slag
2.1	Flexural Strength Test Results (Rai et al(2011))
2.2	Compressive Strength of Concrete with Varying Percentage of Marble Waste (Rai et al(2011))
2.3	Concrete with variation for Cement Replacement (Aliabdo et al (2013))
2.4	Concrete with variation for Sand Replacement (Aliabdo et al (2013))
2.5	SEM micrographs for Various Mixes (Kumar et al (2008))
2.6	Effect of Fly Ash on Cylinder Compressive Strength of BFS Concrete at 28 days (Singha Roy,2011)
2.7	Effect of SP dosage on slump loss (Alsadey, 2011)
2.8	Slump flow (Othmane et al, 2012)
3.1a	Marble Dust Used For Experimental Work
3.1b	Furnace Slag Production in Industry
3.2	X-Ray Diffraction of Iron Furnace Slag
4.1	Compressive strength test setup
4.2	Variation of compressive strength of concrete with different % replacement level of marble dust at different age
4.3	Variation of compressive strength of concrete with different % replacement level of furnace slag at different ages
4.4	Variation of compressive strength of concrete with different % replacement level of furnace slag for 5% MD at different curing ages
4.5	Variation of compressive strength of concrete with different % replacement level of furnace slag for 10% MD at different curing ages
4.6	Variation of compressive strength of concrete with different % replacement level of furnace slag for 15% MD at different ages

Figure no.	Title
4.7	Percentage Variation in Compressive Strength of various mixes as compared to the normal mix at 7 days
4.8	Percentage Variation in Compressive Strength of various mixes as compared to the normal mix at 28 days
4.9	Percentage Variation in Compressive Strength of various mixes as compared to the normal mix at 56 days
4.10	Test setup for flexural strength
4.11	Variation of flexural strength of concrete with different % replacement level of marble dust at different curing ages
4.12	Variation of flexural strength of concrete with different % replacement level of furnace slag at different curing ages
4.13	Variation of flexural strength of concrete with different % replacement level of furnace slag for 5 % MD at different curing ages
4.14	Variation of flexural strength of concrete with different % replacement level of furnace slag for 10% MD at different curing ages
4.15	Variation of flexural strength of concrete with different % replacement level of furnace slag for 15% MD at different curing ages
4.16	Percentage Variation in Flexural Strength of various mixes as compared to the normal mix at 7 days
4.17	Percentage Variation in Flexural Strength of various mixes as compared to the normal mix at 28 days

1.1. IMPACT OF MODERN CONCRETE USE

Concrete is widely used for making architectural structures, foundations, brick/block walls, pavements, bridges/overpasses, highways, runways, parking structures, dams, pools/reservoirs, pipes, footings for gates, fences and poles and even boats. Concrete is used in large quantities almost everywhere mankind has a need for infrastructure. The amount of concrete used worldwide, ton for ton, is twice that of steel, wood, plastics, and aluminum combined. Concrete's use in the modern world is exceeded only by that of naturally occurring water. Concrete is also the basis of a large commercial industry. Globally, the ready-mix concrete industry, the largest segment of the concrete market, is projected to exceed \$100 billion in revenue by 2015. In the United States alone, concrete production is a \$30-billion-per-year industry, considering only the value of the ready-mixed concrete sold each year. Given the size of the concrete industry, and the fundamental way concrete is used to shape the infrastructure of the modern world, it is difficult to overstate the role this material plays today. In modern times, researchers have experimented with the addition of other materials, like water-based cross linking polymers, to create concrete with improved properties, such as higher strength, electrical conductivity, or resistance to damages through spillage.

1.2 INTRODUCTION TO CONCRETE PAVEMENTS

A pavement is a multi-layered structural part of the road which is subjected to stresses imposed by vehicular loading applied, as well as to deterioration from the effects of weather and the abrasive action of moving traffic. A satisfactory pavement design is one that is able to withstand these effects for a required period of time. A pavement consists of a multi-layer system, which is formed of a number of layers of compacted unbound aggregates or bound materials. Pavements, in general, can be classified in two major categories: concrete pavements and bituminous pavements. Concrete pavements are generally called rigid pavements and bituminous pavements as flexible pavements. There could be some other types of pavements which are neither rigid, nor flexible, for example, block pavement, composite pavements etc.

There are three main components of a road pavement

1. Foundation

2. Base

3. Surfacing

The foundation comprises of sub grade soil (cut or fill), capping and sub-base. The foundation is designed to provide a certain standard quality of support for the higher layers. The base is the main structural layer of the pavement. Meanwhile, an asphalt surfacing comprises of a surface course and a binder course. The function of the surfacing is to enable good ride quality to be combined with appropriate resistance to skidding and resistance to crack formation.

A concrete pavement, in general, consists of three layers, comprising of a sub-grade, base layer and the concrete slab. Generally bound base layers are used for concrete pavement construction. As per Indian specification, some example of such base layers are Dry Lean Concrete (DLC), Roller Compacted Concrete (RCC) (IRC:15-2002).The concrete slab is generally of M40 to M50 grade of concrete as per Indian specifications, and is called as paving quality concrete (PQC).

1.2.1 Components of Concrete Pavement:

The main components of concrete pavement are discussed as below:

1) Sub grade 2) capping layer 3) drainage layer

1) Sub grade: Sub grade is not formally a pavement layer. However, its properties and function must be fully understood in order to design and construct a satisfactory pavement over it. Sub grade is the natural soil or made-up ground (fill) on which the pavement is built. The function of the sub grade is to support the load of the whole pavement.

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

- No soft spots be present in the sub-grade or sub-base.
- The uniformly compacted sub-grade or sub- base should extend 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 Kg/cm³.

2) Capping layer: Over a weak sub grade a capping may be provided to act as a sub grade improvement layer. It can also be used as a working platform and prevents deterioration of

the sub grade. This layer usually uses a relatively low quality, cheap, locally available aggregate. Some recycled materials are also used as an alternative material to make a capping. Occasionally, a stabilizer such as cement or lime is incorporated into the upper part of the sub grade to improve the strength and bearing capacity of the sub grade soil.

3) Geo-composite Drainage layer

Over a sub grade layer a geo-composite drainage layer is provided for improved pavement drainage. A geo-composite has many advantages over natural drainage materials in maintaining its flow capacity and compressive stiffness under construction and service, besides unequal support. It is a sand /graded gravel layer.

The concrete used in these pavements can be further classified as either DLC or PQC, which are briefly discussed as below:

i) 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 is 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)

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

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 maximum size of the coarse aggregate shall be 31.5 mm.

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 1.2). Fine

aggregate shall be free from soft particles, clay, shale, loam, cemented particles, mica, organic and other foreign matter.



Fig 1.1 Pavement Dry Lean Concrete

Table: 1.1 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

Table: 1.2 Fine aggregates (IS 383-1970)

IS 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	75-10	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

The material passing IS Sieve No.75 micron should not exceed the following:

i) for natural sand (Uncrushed)	3.0 percent
ii) for 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 1.3.

Table: 1.3 Aggregate Gradations for Dry Lean Concrete

Sieve Designation	Percentage by weight passing the Sieve
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

- d) *Proportioning of Materials for the Mix:* The mix design shall be done as per IRC: SP: 49. The OPC content shall not be less than 135 kg/m³ in case of blending at site. The curing period may be suitably enhanced (by at least about 2 days). 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.
- e) *Moisture content:* The right amount of water for the lean concrete in the main work shall be decided so as to ensure full compaction under rolling and shall be assessed at

the time of rolling the trial length. Too much water will cause the lean concrete to be heaving up before the wheels and picked up on the wheels of the roller and too little will lead to inadequate compaction, a low in-situ strength and an open-textured surface. The optimum water content shall be determined and demonstrated by rolling during trial length construction and the optimum moisture content and degree of compaction shall be got approved from Engineer. While laying in the main work, the lean concrete shall have moisture content between the optimum and optimum +2 percent, keeping in view the effectiveness of compaction achieved and to compensate for evaporation losses.

- f) *Cement Content*: The minimum cement content in the lean concrete shall be 150 kg/m³ 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/m³. If this minimum cement content is not sufficient to produce concrete of the specified strength.
- g) *Water*: Water used for mixing and curing of concrete shall be clean and free from injurious amounts of oil, salt, acid, vegetable matter or other substances harmful to the finished concrete. It shall meet the requirements stipulated in IS:456
- h) *Concrete Strength*: The average compressive strength of each consecutive group of 5 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.

Dry Lean Concrete acting as sub-base to the Paving Quality Concrete (PQC) shall be laid only on a granular sub-base/drainage layer. A day before placing of the sub base/drainage layer, the sub-grade surface shall be given a fine spray of water and should be rolled with one or two passes of a smooth wheeled roller. If necessary, another fine spray of water may be applied just before placing drainage layer. If the sub grade CBR is less than 8 percent, the sub-grade shall be stabilized with lime, cement or any other stabilizer accredited by IRC or by mechanical stabilization so as to raise the CBR to not less than 15 percent in the field.

ii) Paving Quality Concrete (PQC): It is the top most layer of the concrete pavement which consists of an un-reinforced, dowel jointed, plain cement concrete slab, where the thickness depend upon the loading type, if load is more, more will be the thickness of the slab. Fig 1.2 shows the paving quality concrete slab.

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

- a) *Cement*: Any of the cements, as mentioned in Table can be used for manufacturing PQC.
- 1) Fly ash up to 20 percent by weight of cement may be used in ordinary Portland cement 53 Grade. No fly ash shall be used in any other grade of Cement other than 53 Grade. The fly ash shall conform to IS: 3812 (Part I).
 - 2) Ground Granulated Blast Furnace Slag (GGBFS) obtained by grinding granulated slag conforming to IS: 12089. GGBFS shall not be used in any other grade of cement except 53 grade. The content of GGBFS shall be up to 50 percent by weight of Ordinary Portland Cement 53 grade.
 - 3) Mix design will be done as per IRC:44. The OPC content shall not be less than 310 kg/m³ in case of blending at site. The curing period may be suitably enhanced by at least about 2 days.



Fig 1.2 pavement quality concrete

- b) *Coarse aggregates*: The maximum size of coarse aggregate shall not exceed 31.5 mm for pavement concrete. No aggregate which has water absorption more than 2 percent shall be used in the concrete mix. The aggregates shall be tested for soundness in

accordance with IS: 2386 (Part-5). After 5 cycles of testing, the loss shall not be more than 12 percent if sodium sulphate solution is used or 18 percent if magnesium sulphate solution is used. The combined flakiness and elongation index of aggregate shall not be more than 35 percent.

- c) *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.
- d) *Cement content*: When Ordinary Portland Cement (OPC) is used the quantity of cement shall not be less than 360 kg/cum. In case fly ash grade I (as per IS:3812) is blended at site as part replacement of cement, the quantity of fly ash shall be up to 20 percent by weight of cement and the quantity of OPC in such a blend shall not be less than 310 kg/cum. The minimum of OPC content in case ground granulated portland blast furnace is used, shall also not be less than 310 kg/m³.
- e) *Chemical Admixtures*: Admixtures conforming to IS:9103 and IS:6925 shall be permitted to improve workability of the concrete or extension of setting time, on satisfactory evidence that they will not have any adverse effect on the properties of concrete with respect to strength, volume change, durability and have no deleterious effect on steel bars. The particulars of the admixture and the quantity to be used must be furnished to the Engineer in advance to obtain his approval before use. Satisfactory performance of the admixtures should be proved both on the laboratory concrete trial mixes and in the trial length paving. If air entraining admixture is used, the total quantity of air in air-entrained concrete as a percentage of the volume of the mix shall be 5±1.5 percent for 31.5 mm nominal size aggregate.
- f) *Fibres*: Fibres may be used subject to the provision in the design/approval by the Engineer to reduce the shrinkage cracking and post-cracking. The fibres may be steel fibre as per IRC: SP 46.
- g) *Mild steel bars for dowels and tie bars*:
 - i) Dowel Bar shall be of plain mild steel conforming to IS:432 and will have yield stress of Fe-240.
 - ii) Tie bar shall be of TMT steel conforming to IS:1786 and will have yield stress of Fe-500.
- h) *Pre-moulded joint filler*: Joint filler board for expansion joints shall be used only at abutting structures like bridges and shall be of 20-25 mm thickness within a tolerance of ± 1.5 mm and of a firm compressible material and complying with the requirements

of IS:1838, or BS:2630 “Preformed Joint Filler”. It shall be 25 mm less in depth than the thickness of the slab within a tolerance of ± 3 mm and provided to the full width between the side forms. It shall be in suitable lengths which shall not be less than one lane width. Holes to accommodate dowel bars shall be accurately bored or punched out to give a sliding fit on the dowel bars.

- i) *Joint sealing compound*: The joint sealing compound shall be of hot poured, elastomeric type or cold polysulphide/polyurethane/silicon type having flexibility, resistance to age hardening and durability as per IRC:57
- j) *Concrete strength*: The characteristic flexural strength of concrete shall not be less than 4.5 MPa (M 40 Grade). Quality control in the field shall be exercised on the basis of flexural strength. It may, however, be ensured that the materials and mix proportions remain substantially unaltered during the daily concrete production. The water content shall be the minimum required to provide the agreed workability for full compaction of the concrete to the required density as determined by the trial mixes or as approved by the Engineer and the maximum free water cement ratio shall be 0.45 when only OPC is used and 0.50 when blended cement (Portland Pozzolana Cement or Portland Slag Cement or OPC blended with fly ash or Ground Granulated Blast Furnace Slag at site) is used.

1.2.2 Joints in Concrete Pavements

Joints shall be constructed depending upon their functional requirement. They are provided in concrete road expansion, contraction and warping of slabs due to the variation in the temperature. The location of the joints should be transferred accurately at the site and mechanical saw cutting of joints done as per stipulated dimensions. It shall be ensured that the required depth of cut is made from edge-to-edge of the pavement. Transverse and longitudinal joints in the pavement (PQC) and DLC sub-base shall be staggered so that they are not coincident vertically and are at least 800 to 1000 mm and 300 to 400 mm apart respectively. Initial cut or slot not less than 3 mm and a depth of 1/4th to 1/3rd depth of the slab at transverse or longitudinal joint as soon as concrete hardens. During summer (temp $>30^{\circ}\text{C}$), cutting may be carried after 4-8 hours of laying, whereas, when the temperature is less than 30°C , joint cutting may be done after 8-12 hours of laying. When the kerb is cast integrally with the main pavement slab, the joint cutting shall also be extended to the kerb. When on instructions of the Engineer, the use of maturity meter is specified; sawing

should not be initiated when the compressive strength of the concrete is less than 2 MPa and should be completed before it attains the compressive strength of 7 MPa. The various requirements of good joints include:

- Joint must move freely
- Joints must not allow infiltration of rain water and ingress of stone grits
- Joints must not protrude out the general level of the slab
- It is desirable that joint be constructed in the line across the full width of pavement. Staggered or skew joints are not desirable.

a) *Transverse joints*: Transverse joints shall be contraction and expansion joints constructed at the spacing described in the drawings. Transverse joints shall be straight within the following tolerances along the intended line of joints which is the straight line transverse to the longitudinal axis of the carriageway. (MORTH section 600). The deviations of the filler board in the case of expansion joints from the intended line of the joint shall not be greater than ± 10 mm, also, the best fit straight line through the joint grooves as constructed shall be not more than 25 mm from the intended line of the joint. The deviations of the joint groove from the best fit straight line of the joint shall not be greater than 10 mm.

b) *Contraction joints*: These are purposely made weakened planes which relieve the tensile stresses in the concrete caused due to changes in the moisture content (Drying shrinkage) and/or temperature and prevent the formation of irregular cracks due to restraint in free contraction of concrete. They are also provided to

- Relieve stresses due to warping
- To permit the contraction of the slab
- The spacing of contraction joint should be limited to 4.5m (IRC 15). Fig shows the contraction joint details in slab. Joints 3 to 5mm wide are to be cut to $1/3$ to $1/4$ depth. Dowel bars (MS Rounds) are to be placed at mid depth and covered with thin plastic sheathing for $2/3$ length. Fig 1.3a shows the contraction joint in slab.



Fig1.3a Dowel bar used in a contraction joint (D.V .Bhavanna Rao)

- c) *Expansion joints*: They are full-depth joints provided transversely, into which pavement can expand, thus relieving compressive stresses due to expansion of concrete slabs, and preventing any tendency toward distortion, buckling blow-up and spalling. These joints are very difficult to maintain and they get filled up with dirt etc. causing locking of joints. They are therefore not in use. These joints are provided only when concrete slab abuts with bridge or culvert.
- d) *Longitudinal joints*: Lanes are jointed together by joint known as longitudinal joint. These are provided in multilane pavement and also when the pavement is more than 4.5m wide. They are provided normally at 3.5m c/c to
- Relieve stresses due to warping.
 - To allow differential shrinkage & swelling due to changes of sub grade moisture
 - To prevent longitudinal cracking

Fig1.3b shows the detailing of longitudinal joint. Joints are to be saw cut to $1/3^{\text{rd}}$ slab thick $\pm 5\text{mm}$. bar are to be placed middle third of slab thickness.

- e) *Transverse construction joint*: Transverse construction joint shall be placed whenever concreting is completed after a day's work or is suspended for more than 30 minutes. These joints shall be provided at location of constructing joints using dowel bars. The construction joints may preferably coincide with the pre-specified location of construction joints by properly planning the day to day concreting work of PQC. The joint shall be made butt type. At all construction joints, steel bulk heads

shall be used to retain the concrete while the surface is finished. The surface of the concrete laid subsequently shall conform to the grade and cross sections of the previously laid pavement. When positioning of bulk head/stop-end is not possible, concreting to an additional 1 or 2 m length may be carried out to enable the movement of joint cutting machine so that joint grooves may be cut and the extra 1 or 2 m length is cut out and removed subsequently after concrete has hardened. Fig1.3b shows tie roads are used for longitudinal joint in concrete.



Fig1.3b Tie roads are used for longitudinal (D.V .Bhavanna Rao)

- f) *Dowel bars*:Dowel bars shall be mild steel rounds free from oil, dirt, loose rust or scale. They shall be straight, free of irregularities and burring restricting slippage in the concrete. Dowel bars provide load transfer to relieve part of load stresses in edge and corner regions at transverse joints. Coated Dowel bars are often to prevent corrosion. These are assumed to transfer about 40% of wheel load. Dowel bars embedded and fix in concrete at one end and kept free to expand/contract at the other end. Spacing between the dowel bars normally 30cm and size varies from 25-38mm & length 36-50cm. fig shows the necessity of providing dowel bars.

1.3 MARBLE DUST

Marble Dust (MD) is a very fine powder, obtained as a by-product of marble during the sawing and the shaping, and not recycling it due to environmental problems in the world. Marble is a metamorphic rock resulting from the transformation of a pure limestone. The purity of the marble is responsible for its color and appearance; it is white if the limestone is composed solely of calcite (100% CaCO_3). Marble is used for construction and decoration, is durable, has a noble appearance, and is consequently in great demand. Chemically, marbles are crystalline rocks composed predominantly of calcite, dolomite minerals. The other mineral constituents vary from origin to origin. Quartz, muscovite, tremolite, actinolite, micro line, talc, garnet, osterite and biotite are the major mineral impurities whereas SiO_2 , limonite, Fe_2O_3 , manganese, $3\text{H}_2\text{O}$ and FeS_2 (pyrite) are the major chemical impurities associated with marble. The main impurities in raw limestone (for cement) which can affect the properties of finished cement are magnesia, phosphate, leads, zinc, alkalis and sulfides.

India is among the top world exporters of marble stone. The Indian marble industry has been growing steadily at an annual rate of around 10% per year. Cutting of stones produces heat, slurry, rock fragments and dust. 20 to 30% of marble blocks are converted into powder. 3,172 thousand tons of marble dust was produced in year 2009-10 thus leaving these waste materials to the environment directly can cause environmental problem.

1.3.1 Use of marble dust as replacement material in concrete

In building industry, Marble has been commonly used as a building material since the ancient time. Today, the advancement of concrete technology can reduce the consumption of natural resources and energy sources which in turn further lessen the burden of pollutants on the environment. Presently, large amount of marble dust are generated in natural stone processing plants with an important impact on the environment and humans. In India, marble dust is settled by sedimentation and then dumped away which results in environmental pollution, in addition to forming dust in summer and threatening both agriculture and public health. Therefore, utilization of the marble dust in various industrial sectors especially the construction, agriculture, glass and paper industries would help to protect the environment. Hence the reuse of waste material has been emphasized. Waste can be used to produce new products or can be used as admixtures so that natural resources are used more efficiently and the environment is protected from waste deposits. There are several reuse and recycling solutions for this industrial by-product.

Marble powder can be used as an admixture in concrete, so that strength of the concrete can be increased. Marble dust is mixed with concrete, cement to make blocks, building stones, floors and many other objects. Also the concrete production impact the environment with CO₂ emission which causes global warming during production of cement. Marble dust (MD) can be used to improve the mechanical and physical properties of the conventional concrete, the possibility of utilizing MD as an alternative very fine aggregate in the production of concrete will also induce a relief on waste disposal issues. Now-a-days the cost of material is increasing so if we use the waste material in the production of the concrete so we decrease the price.

1.3.2 Chemical composition of marble dust

Marble dust consist a high percentage of CaO and SiO₂.it consists of mainly 40% amount of CaO and 28% SiO₂.

Table 1.4 chemical composition of marble dust (BaharDemirel, 2010)

Oxide compound	Mass percentage
CaO	40.45
Al ₂ O ₃	.42
SiO ₂	28.35
Fe ₂ O ₃	9.70
MgO	16.25

1.3.3 Physical properties of marble dust (BaharDemirel, 2010)

The Specific surface area (cm²/gm) for marble is 11.4×10³ and has a Bulk density (kg/m³) of 986. The Specific gravity of marble is 2.5 and having colour of Light gray.

1.4 BLAST FURNACE SLAG

Blast furnace slag is a non-metallic by-product produced in the process of iron production by chemical reduction in a blast furnace. It consists primarily of calcium silicates, alumina silicates, and calcium-alumina-silicates.

1.4.1 Production of Blast Furnace slag

In the production of iron, the blast furnace is charged with iron ore, fluxing agents (e.g. limestone and dolomite) and coke as fuel and the reducing agent. The iron ore is a mixture of iron oxides, silica and alumina. From this and the added fluxing agents, alkaline earth carbonates, molten slag and iron are formed. Oxygen in the preheated air is blown into the

furnace where it combines with the carbon in the coke to produce the needed heat and carbon monoxide. At the same time, the iron ores are reduced to iron, mainly through the reaction of the carbon monoxide with iron oxide to yield carbon dioxide (CO₂) and metallic iron. The fluxing agents dissociate into calcium and magnesium oxides and carbon dioxide. The oxides of magnesium combine with silica and alumina to form slag (blast furnace slag). Fig 1.4 represents the flow chart for the production of slag.

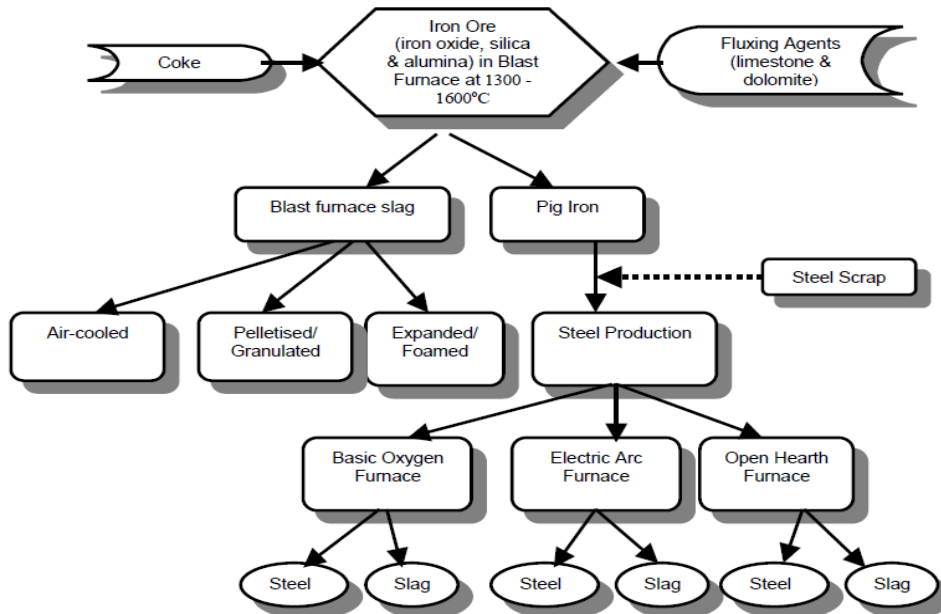


Figure 1.4 Production of blast furnace & steel slag (Yusof,2006)

1.4.2 Properties of Blast Furnace Slag (Yusof ,2006)

Blast-furnace slag is consistent in its physical properties as would be expected for a particular source of natural aggregate. The principal constituents of blast furnace slag are silica (SiO₂), alumina (Al₂O₃), calcia (CaO) and magnesia (MgO). Minor elements include manganese, iron, and sulphur compounds as well as trace amounts of several others.

a) Chemical Properties

The principal constituents of blast furnace slag are silica (SiO₂), alumina (Al₂O₃), calcia (CaO) and magnesia (MgO) which make up 95% of the composition According to Sherwood (1995), blast furnace slag is not a pozzolan, nor in itself cementitious, but it possesses latent hydraulic properties, which can be developed by the addition of an activator such as lime or another alkaline material. However, when ground to a proper fineness, the chemical compositions and glassy nature of vitrified slag are such that when combined with water, the vitrified slag reacts to form a pozzolanic product (by cementitious hydration). The

magnitude of these cementitious reactions depends on the chemical composition, glass content and fineness of the slag. Blast furnace slag is mildly alkaline and exhibits a pH in solution in the range of 8 to 10. Table 1.6 shows the chemical properties of air-cooled blast furnace slag.

Table 1.6: Typical chemical properties of blast-furnace slag (*National Slag Association, 1985*)

Properties	Value (%)
Calcium oxide (CaO)	34 – 43
Silicon dioxide (SiO ₂)	27 – 38
Aluminium oxide (Al ₂ O ₃)	7 – 12
Magnesium oxide (MgO)	7 – 15
Iron (FeO or Fe ₂ O ₃)	0.2 – 1.6
Sulphur (S)	1.0 – 1.9
Manganese oxide (MnO)	0.15 – 0.76

b) Physical Properties

The physical characteristics of blast furnace slag such as density, porosity and particle size are affected by the cooling rate (i.e. cooling method) of the slag and its chemical composition. Air-cooled blast furnace slag is angular, roughly cubical and has textures ranging from rough, vesicular (porous) surfaces to glassy surfaces with conchoidal fractures. When it is crushed and screened, its physical properties make it particularly suitable as an aggregate, both coated and uncoated. It has a rough surface texture giving good frictional properties and good adhesion to bituminous and cement binders, a low coefficient of thermal expansion and a high fire resistance.

1.4.3 The Use of BF Slag in Road Construction (*Yusof, 2006*)

Blast-furnace slag has been used in many fields such as Portland cement concrete, granular base, asphalt pavement and embankment, fill materials, concrete aggregate, mineral wool, and railroad ballast. Because there is no significant risk, the EC has eliminated blast-furnace slag from its waste schedule. For quality control of blast furnace slag production, the British Standard Institution has produced some standards such as BS 1047 (1983) and BS 3797 (1990) to be followed. The UK Highway Agency has allowed the use of blast furnace slag in bulk fill, capping, unbound sub-base, bitumen bound layers and cement bound layers,

cement. However, the use of blast furnace slag in road construction shall follow specifications. some of the specifications to be followed when using blast furnace slag in construction as listed below:

- Total sulphur content must be not greater than 2% (as S) for concrete aggregate.
- Sulphate content must be not more than 0.7% (as SO₂)
- Water-soluble sulphate content must not exceed 2.0 g/l for unbound material.
- Blast furnace slag must not have absorption of more than 10%.
- Flakiness index (FI) of coarse aggregate must not exceed 35.
- Ten percent fines value must be not less than 50 kN.
- Bulk density of compacted blast furnace slag in the range 10 to 14 mm must be not be lower than 1.1 Mg/m³.

1.4.4 Problems arising from the Use of BF Slag in Road Construction (Yusof,2006)

Although air-cooled blast furnace slag has been successfully used in many areas, there is still a need to evaluate factors that contribute to the lack of consistency in the physical properties (gradation, specific gravity, absorption and angularity) of the slag aggregate produced among individual slag producers. Besides that, it is also important to study its effect on performance problems such as flushing and raveling in hot mix asphalt. In addition, formal quality control procedures should be instituted to monitor the quality of specific air-cooled blast furnace slag sources to assist in mitigating these problems.

1.5 SCOPE OF PRESENT WORK

The main objective of the proposed work is to study the effect of use of marble dust and furnace slag as partial replacement of sand for the production of Pavement Quality Concrete. The effect of marble dust and furnace slag has been studied on the strength characteristics of Pavement Quality Concrete.

2.0 GENERAL

Many researchers have investigated various properties of concrete containing by-products and waste materials produced from various industrial processes such as Ground Granulated Blast-furnace Slag (GGBS), fly ash, silica fume, marble dust etc. as mineral admixtures, aggregate replacements or binding material etc. Equal or higher strength can be achieved by using artificial supplementary cementing materials as replacement of aggregates, at the same time, a similar or higher durability can also be achieved with significant ecological benefits.

2.1 USE OF MARBLE DUST IN CONCRETE

Topcu et al (2008) studied the effect of waste marble dust content as filler on properties of self-compacting concrete which can be used in transportation structures like bridges and tunnels. The marble dust was used as additional filler in the mix and was replaced up to 50%. For a constant range of flow value the super plasticizer was varied in the various mixes. In 0% MD mix the amount used was 2.5% of the binder content and in 10 % MD mix it was 2.2 % which showed that the requirement of super plasticizer decreased with increasing marble dust content, as it was only 1.1 % for the 50% mix. It indicated that the workability of the mixes improved as the marble dust content is increased in the mix. It also shows that the compressive strength decreased as we increased the MD content in the filler (i.e. cement +fly ash); the percentage decrease in compressive strength being low for mixes having up to 20% MD content and was of the order of only 3% , and for the 50% MD it was about 50% lower than the control mix. In case of flexure strength, it followed similar variation as that for compressive strength, with a 55% reduction in strength for 50% MD mix. The loss in strength is advocated to the increase in demand for the cement as the marble powder has large surface area.

Ali (2010) investigated the mechanical properties of the concrete which is suitable to use as construction of all types of structures (building, bridges, roads) contain the marble dust as a partially cement replacement at w/c .5. The results shows that 7 days and 28 days compressive strength increase for 5% MD replacement and the percentage of increase was 11% and 10% respectively for the days. Further increase in the content of marble dust,

there was a decrease in the strength for the mix having 10% MD. In the other hand for the mix 5% MD and 7.5% MD there is no effect on the flexure strength and for the 10% MD mix there is very little decrease of 2%. The increase in compressive strength could be explained with pore-filling effect of fine-ground limestone powder, providing suitable nucleus for hydration and catalyzing the hydration. The usage of WMP reduced the porosity in concrete matrix physically, and had an important binding property which was developed by hydration of calcite and C_3A chemically. The use of WMP in combination with super plasticizing admixture allowed for compensating the high water demand of marble powder itself.

Demirel et al (2010) experimentally studied the effects of using waste marble dust (WMD) as a fine material on the mechanical properties of the concrete. For this purpose four different series of concrete-mixtures were prepared by replacing the fine sand (passing 0.25 mm sieve) with WMD at proportions of 0, 25, 50 and 100% by weight. In order to determine the effect of the WMD on the compressive strength with respect to the curing age, compressive strengths of the samples were recorded at the curing ages of 3, 7, 28 and 90 days. Water-cement ratio was adopted .50. It was seen from the observation that the compressive strength had increased with the increase WMD content. There was an increase of about 10% for the M100%, this may not be only due to the filling of the voids in the concrete mix but also due to the little cement properties of marble dust by providing an extra amount of cement in the mix.

Hebhoub et al (2010) demonstrated the possibility of using marble wastes as a substitute rather than natural aggregates in concrete production, experimental investigation was carried out on three series of concrete mixtures: sand substitution mixture, gravel substitution mixture and a mixture of both aggregates (sand and gravel). The concrete formulations were produced with a constant water/cement ratio of .5. The compressive strength for the all the mix in sand substitution increased except 100% replacement for sand. The 50% replacement of MD as sand had a highest increase of 20% to that of control mix and in case of coarse aggregate 75% MD replacement shows an increase of 25 %.

Rai et al (2011) studied the effect of use of marble dust as a granular material in concrete. In the study the sand was replaced up to 20% with marble granular and the mechanical strength was evaluated and compare with the control mix. By increasing the waste marble granules the compressive strength values of concrete tends to increase. 10% replacement had an 11% increase in strength at 28 days. This trend can be attributed to the fact that

marble granules possess cementing properties. It is also as much effective in enhancing cohesiveness due to lower fineness modulus of the marble powder or granules both. In case of flexural strength there was an increase in the strength up to 15 % replacement. Fig 2.1 shows the variation of flexure strength with the % change for marble granular and Fig 2.2 shows the variation of compressive strength.

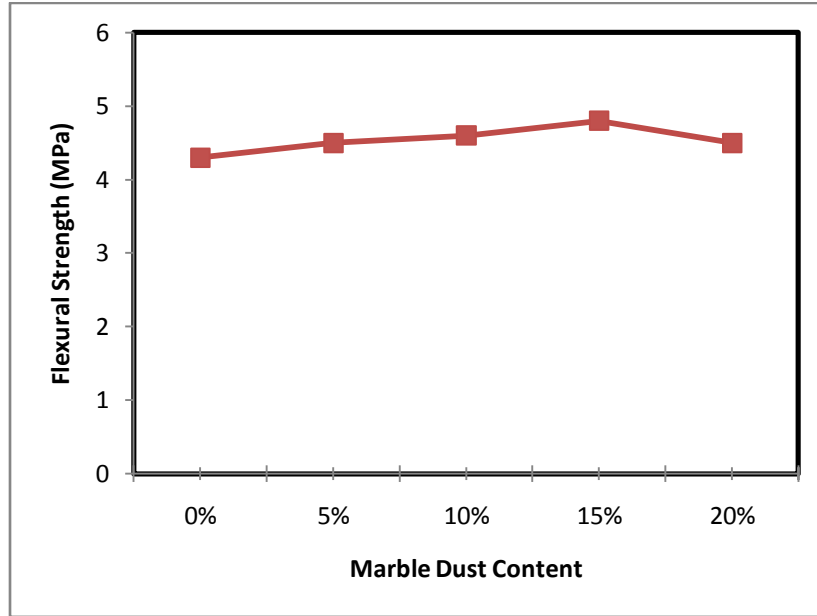


Fig 2.1 Flexural Strength Test Results (Rai et al (2011))

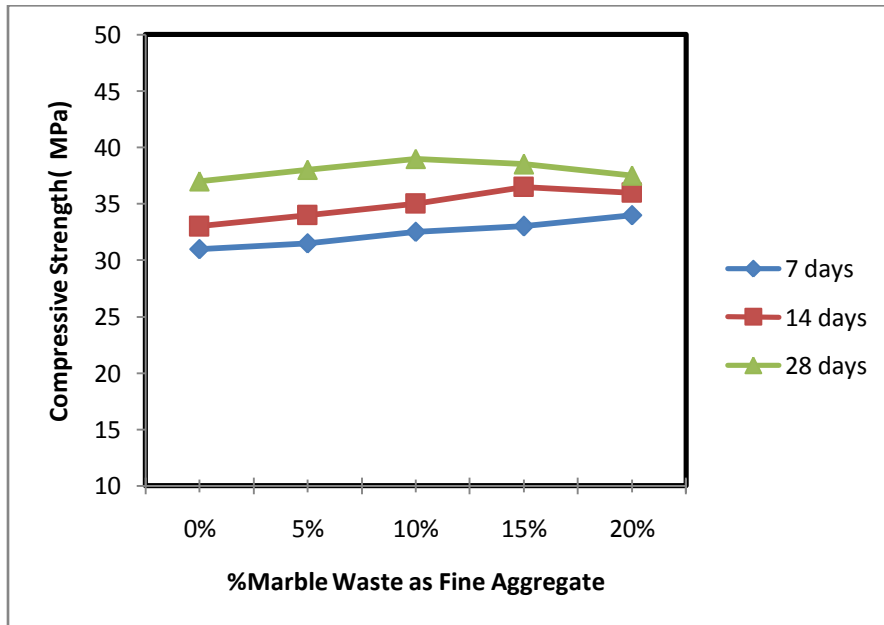


Fig 2.2 Compressive Strength of Concrete with Varying Percentage of Marble Waste (Rai et al (2011))

Aliabdo et al (2013) investigated the possibility of utilizing waste marble dust (MD) in cement and concrete production by discussing the properties of concrete contained marble dust as a cement replacement and as a sand replacement (cement addition). The replacement ratios which have been studied were 0.0%, 5.0%, 7.5%, 10.0% and 15% by weight. Water to cement ratio (w/c) were 0.50 and 0.40 in case of cement replacement and in case of sand replacement, respectively. It was observed that the higher values of marble dust decreases the C_3A content compared to plain cement. For 15% marble dust, there was a decrease of 10% in the compressive strength of concrete. At w/c of 0.5, in all levels of marble dust as a cement replacement, the concrete compressive strength slightly decreases. Most likely this is due to the reduction in cementing material (C_3A and C_2S) which is mainly responsible for concrete strength. But at the w/c of 0.4 there was slightly increase up to the 10% MD. This could be due to the pore-filling effect of fine marble dust that enhances the properties of the transition zone (TZ) surrounding aggregate. Fig 2.3 shows the effect on the compressive strength of concrete with the variation in the MD% as cement replacement at w/c ratio of .40.

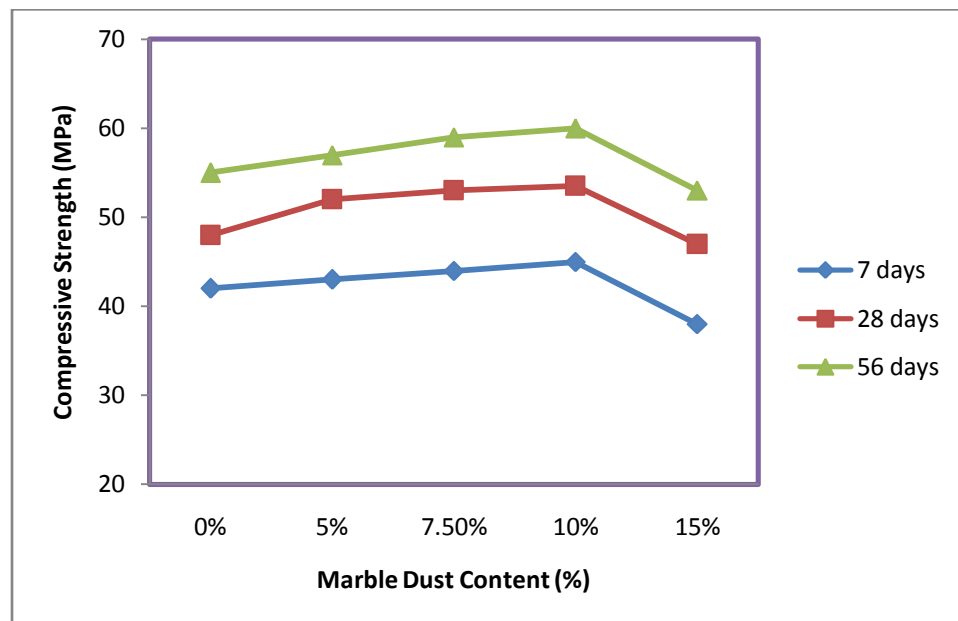


Fig 2.3 Concrete with variation for cement replacement (Aliabdo et al (2013))

Where is the graph for cement replacement or sand replacement?

In the case of sand replacement it was seen that compressive strength increases with the increase of marble dust replacement ratio up to 15% as shown in Fig 2.4.

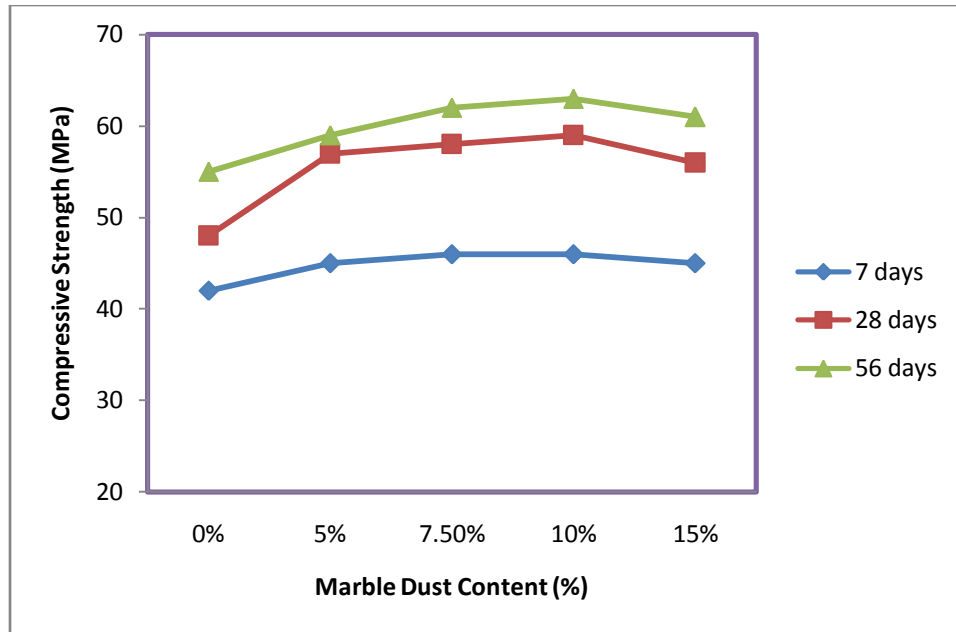


Fig 2.4 Concrete with variation for sand replacement (Aliabdo et al (2013))

This may be due to the effect of marble dust as micro fine filler. This filler effect enhances the cement matrix and transition zone properties. This trend was same for concrete with 0.50 and 0.40 w/c ratio.

Pathan and Pathan (2014) studied the feasibility of the substitution of marble dust for cement to achieve economy and environment saving. They reviewed different literature and concluded that in concrete production replacement of 5% cement by marble waste powder gives comparable compressive and flexural strength as of control concrete specimens; but increasing the replacement range beyond 5% results in strength reduction. In concrete production, replacing of sand up to 20% by marble waste powder gives similar strength as of concrete mixes with 100% sand both at early and latter ages.

2.2 FURNACE SLAG

Hale et al (2007) discussed the properties of concrete mixtures containing slag cement and fly ash for use in transportation structures and studied the influence of slag cement on the fresh and hardened properties of concrete to be used in pavements and bridge structures and also influence of fly ash in the mix concrete which produced mixed effects. The slump for the slag cement mix is generally lower than the control mix, this decrease in the slump attributed to the higher fineness of the slag, as the material becomes finer, the water demand increases due to the increase in surface area per unit volume. The increase in water demand of the slag mixture results in lower slumps. The addition of fly ash therefore

increase the slump due the fact that fly ash is composed of round, smooth glassy particles which often reduces water demand and produces better workability. The results show that the addition of slag cement increased the compressive strength for all mixtures. The average compressive strength of the BFS mixtures was 9.5 MPa greater than the average compressive strength of the control mixtures. This increase in compressive strength is due to the hydraulic reaction of the slag cement with the calcium hydroxide (CH) and available alkalis to form an additional C-S-H. This reaction improves the density of the concrete paste matrix thereby improving the strength. Also in compared to the control mixtures, the addition of slag cement increased the modulus of rupture which is an indication for flexural strength. An increase of 12% in modulus of rupture for the slag mixture was observed.

Kumar et al (2008) used mechanical activation for the slag which was use to replace clinker in the range of 50-95 percentage of slag. Use of activated slag resulted in a remarkable increase in strength of slag cement. Both 1-day and 28-day strength were found to increase with an increase in activated slag content up to 70% slag, due to the increase in the reactivity of the activated slag. In this investigation the activated slag and the commerce slag (without activator) were comparing for the 1 day and 28 day compressive strength. The percentage increase found for 70% activated slag was 15% for 1 day and 35% for 28 days. Fig 2.5 shows the SEM micrographs for the IC-A (40% slag) mix and AMC50S (activated slag 50%).

Teng et al (2010) used the ultra fine ground granulated blast furnace slag (GGBFS) as the partially replaced the cement up to 30% in concrete with water-cement ratios of 0.35 and 0.28. Specific surface area of OPC used was 1466 m²/kg and for ultra fine GGBFS was m²/kg 4968. It shows the increase in compressive strength not on the later ages but also at the early ages (3 day) is about 20% greater than control mix for w/c of 0.28. As the fineness of the UFGGBS is increased, the total surface area for reaction is increased, and this increases the apparent rate of hydration and pozzolanic reactions at early age. The rate of strength development of the concrete improves and the permeability of the concrete is reduced due to reduced total pore volume, pore connection and the better filling of the pore in the Interfacial Transition Zone. The development of flexural strength followed the same trend as that of the compressive strength and the increase percentage in strength is 40%. This seems to suggest that UFGGBS has a greater effect in the flexural strength of the concrete with lower w/c ratio. As the early flexure strength is increase, so utilization of the UFGGBS can have an excellent role in the concrete pavement.

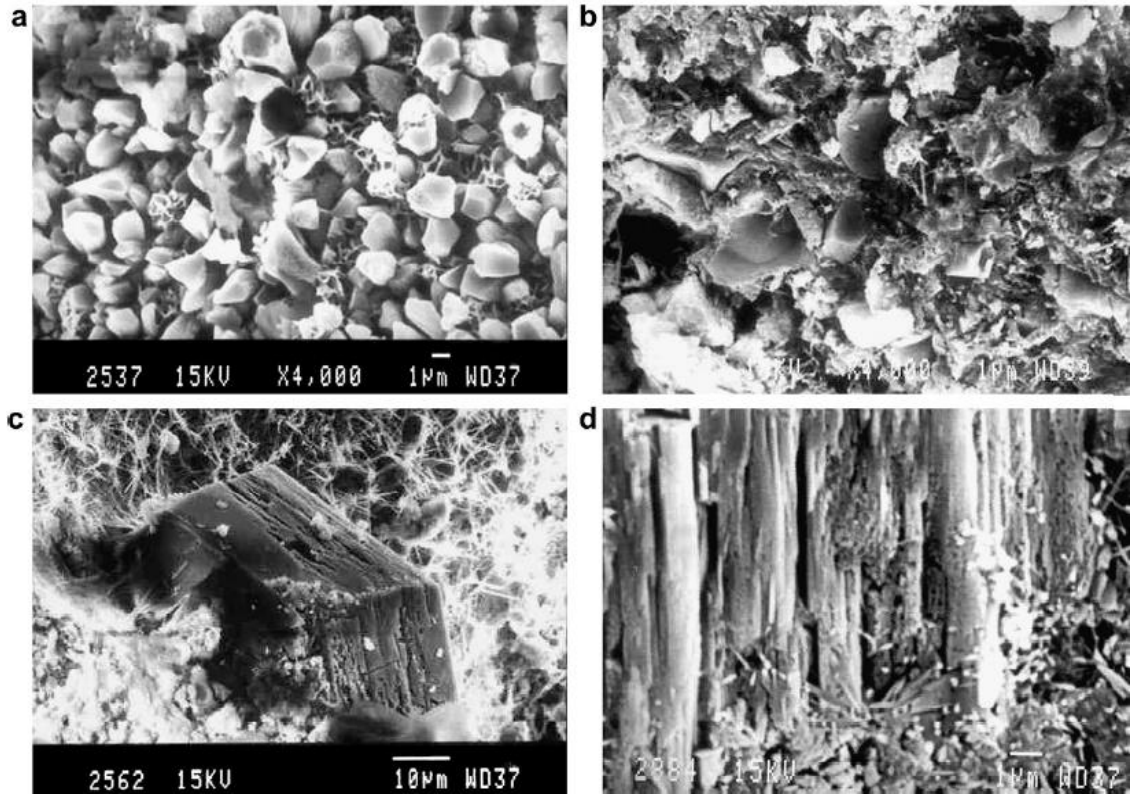


Fig.2.5 SEM micrographs showing (a) mostly non-hydrated slag in IC-A after 1 day hydration, (b) hydrating slag in gel matrix in AMC50S after 1 day hydration, (c) large size portlandite crystal in AMC50S after 1 day hydration, and (d) columnar portlandite crystals in IC-A after 28 days hydration. (Kumar *et al* (2008))

Ettxeberria et al (2010) studied the effect of metallurgical industrial by product as aggregates in concrete. In the experimental work Electric arc furnace slag (EAFS) and blast furnace slag (BSF) were used as substitution for coarse raw aggregates in 25%, 50% and 100% replacement levels for concrete production. Two w/c ratios were used for the concrete mix, w/c of 0.6 and w/c of 0.5.

The results were observed for w/c of 0.5 for concrete produced with EAFS and BFS, and it was found that a higher compressive strength was obtained for the mixes with EAFS and BFS as compared to the control mix. For 100% EAFS coarse aggregate the compressive strength increased by 37% that of control mix and for 100% BFS coarse aggregate the strength increase was 26% when the w/c was 0.5.

Roy (2011) investigated the concrete made of Blast Furnace Slag (BFS) as a coarse aggregates (100%) and Class F fly ash replacing sand up to 60% were used to study the

strength parameters, modulus of elasticity, water absorption and porosity. It was observed that cube compressive strength of concrete containing BFS as coarse aggregate increased with increasing percentage replacement of sand by fly ash in concrete at all ages. Whereas, the flexure strength increased up to the 40% replacement of fly ash as a fine aggregate with 100% BFS coarse aggregate. The increase in the strength in flexure may be due to the angular shape of the coarse aggregates which leads to improvement in the bond between the ingredients of aggregates.

Beyond 40% replacement level the decrease in the strength may be due to the increase in porosity and water absorption in the mix at 28 days. Fig 2.6 shows the variation of flexure strength with the % replacement of fly ash.

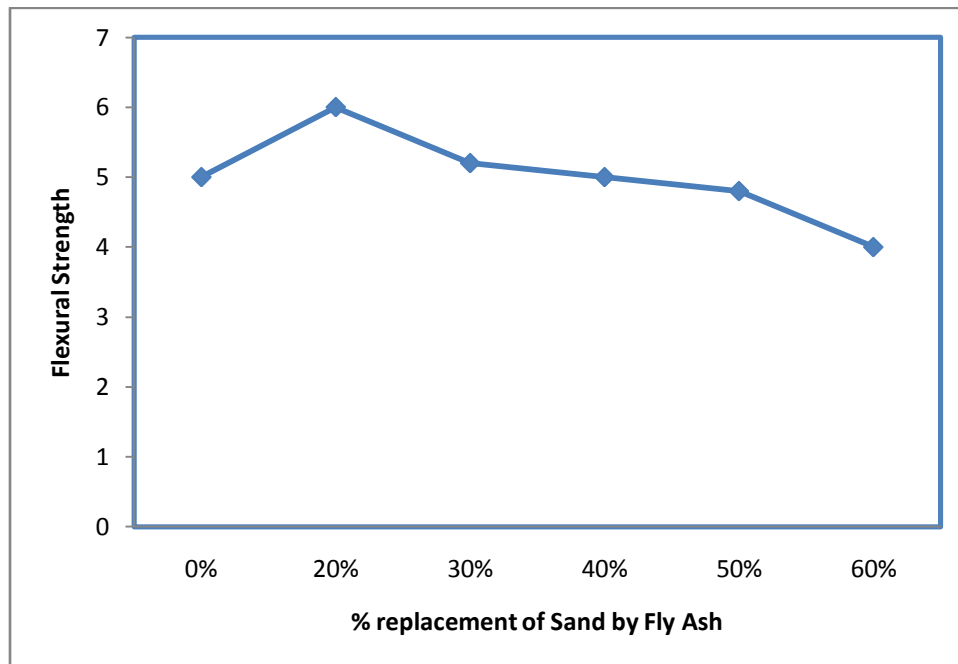


Fig 2.6 Effect of Fly Ash on Cylinder Compressive Strength Of BFS Concrete At 28 Days
(Singha Roy, 2011)

V G. Havanagi et al (2012) investigated the feasibility of local soil and industrial waste materials to replace the conventional construction materials of road embankment and pavement layers with different industrial by-products like copper slag, zinc slag, steel slag, etc. In this study material properties of slag were compared with the conventional material used in roads constructions. The study showed that the specific gravity of the slag (nickel, zinc, steel) was in the range of 2.75 to 3.58. The high specific gravity of copper slag (3.58) and zinc slag (3.5), as compared to sand is due to presence of high content of iron oxide.

From the grain size analysis and Atterberg limit tests, copper slag and zinc slag are classified according to Indian Standard procedure (IS 1498) as SP i.e. poorly graded sand and steel slag is classified as GP i.e. poorly graded gravel. The angle of internal friction of different waste materials varied in the range of 31° to 42° while the value for local soil was 27°. All the waste materials indicated better frictional property and hence show the better shear strength as compared to local soil. It was observed that soaked CBR values of slag varied in the range of 32-70 %, while CBR values of local soil was evaluated as 8 % respectively. All the waste materials have high CBR value as compared to local soil and satisfied the MORTH (2001) criteria for use in sub grade/ sub base layer of road pavement. Copper slag and zinc slag materials can be used as a replacement of fine aggregate in sub base, base (WMM) and bituminous layers of road pavement. The amount of replacement varies from 20 to 30 % in WMM mix and 10 - 25 % in the bituminous mixes.

B G Buddhdev and Dr. H R Varia(2014) investigates the feasibility Study on Application of Blast Furnace Slag in pavement concrete. The comprehensive experimental study was done and the feasibility of BFS used as a fine aggregate in pavement concrete was concluded. In this regard the chemical and physical properties of the BFS were observed in this study. These properties depend upon the raw materials used and methods of processing at plants. The primary characterization indicates the BFS had a enough suitability to utilize as a fine aggregate in production of concrete to enhance the strength and durability of the concrete by saving the natural resources like sand which is day by day become scared.

2.3 EFFECT OF USE OF SUPER PLASTICIZER ON CONCRETE PROPERTIES

Alsadey (2012) studies an experimental program that measures the effects of super plasticizer admixture on the properties of concrete. The Sikament® R2002 was used as a super plasticizer in the mix. To investigate the effects of super plasticizer, four additional mixes was prepared using admixture dosage of 0.6, 0.8, 1.0, 1.2 percentages to the weight of the cement. Fig 2.7 shows the value of slump obtain for the use of different percentage of super plasticizer and shows that increase in the percentage of super plasticizer the workability also increased.

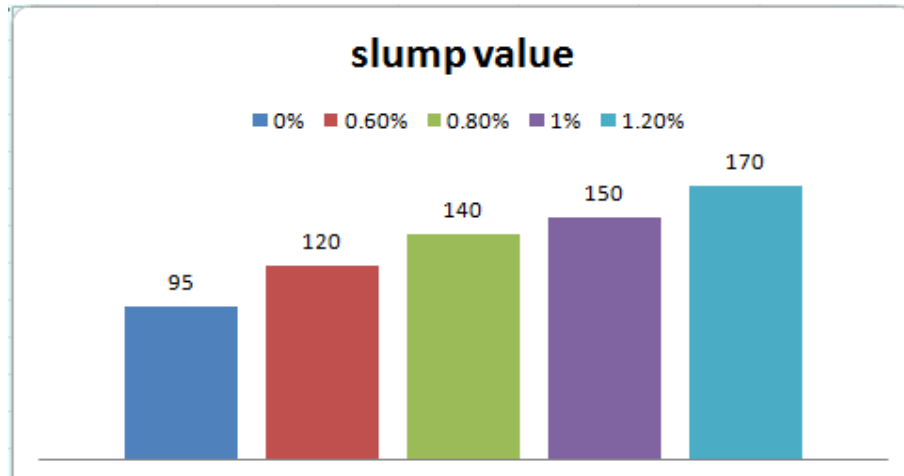


Fig 2.7 Effect of SP dosage on slump loss (Alsadey, 2012)

The compressive strength of the concrete increase up to 1% super plasticizer with an increase of 25% at 28 days. For 1.2% the compressive strength reduces up to 3%.

Othmane et al (2012) investigated the properties of concrete with various percentage replacements of granulated blast furnace slag and super plasticizer type. Two types of super plasticizers: polycarboxylate based super plasticizer and naphthalene sulphonate based super plasticizers were used for the study.

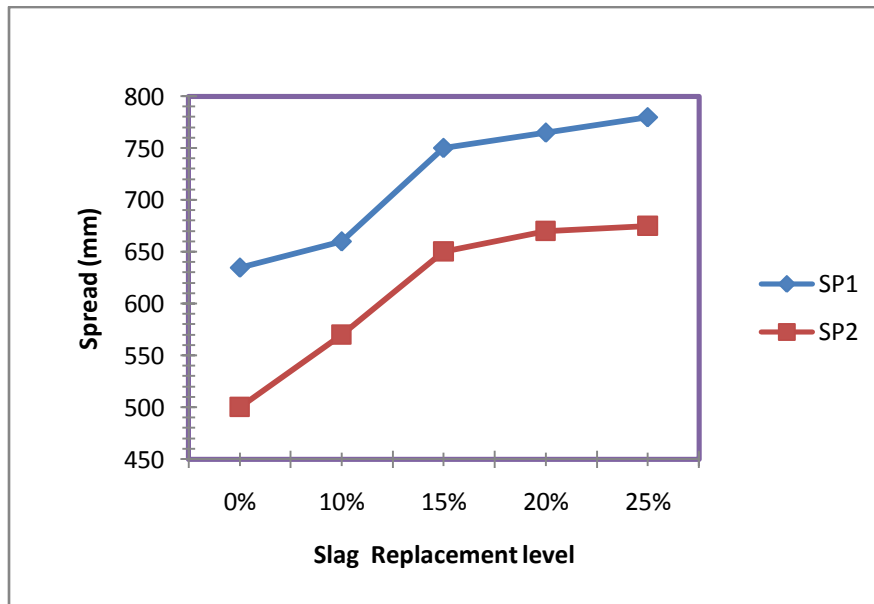


Fig 2.8 Slump flow (Othmane et al, 2012)

The results shows that the SP1 (polycarboxylate based) had better performance than SP2 (naphthalene suulphonate based). The slump flow for the SP1 and SP2 are shown in the Fig.2.8.

Tamrakar et al (2013) compares the properties of super plasticizer based concrete with that of without super plasticizer added concrete. In this research program three different families of super plasticizers had been used. Rheobuild 1125 (Sulphonated naphthalene polymer based) Glenium140 (Polycarboxylic ether polymers) Pozzolith 225 (Modified lignosulphate). The results shows that the properties of concrete in fresh and hardened stages have been improved with the addition of three types of super plasticizer for all nominal mixes of concrete, the Glenium 140(Polycarboxylic ether polymers) have shown however more pronounced in terms of increase in the compressive strength, workability, water reduction, cement saving requirements of concretes.

3.1 GENERAL

The present chapter deals with the materials properties and the results obtained from the various test conducted on the materials used for designing Pavement Quality Concrete (PQC). In order to achieve the objective of the present study, an experiment program was devised to investigate the effect of furnace slag and marble dust, as partial sand replacements, on the compressive and flexure strengths of concrete.

3.2 MATERIALS USED

The properties of material used for making concrete mix are determined in laboratory under controlled conditions as per relevant IS codes of practice. The material characterization was carried out for all the major ingredients of concrete which include cement, coarse aggregates, fine aggregates, super-plasticizer and water, in addition to marble dust and furnace slag. The purpose of the characterization is to check their acceptability as per relevant Indian standards so as to enable an engineer to design a concrete mix for a particular strength. The properties of the various materials, which were used in this study, are presented and discussed in the succeeding sub-sections:

3.2.1 Portland Cement

Cement is the most active component of concrete and usually has the greatest unit cost, thus, its selection and proper use are important in obtaining most economical balance of properties desired for any particular concrete mixture. It fills up voids existing in the fine aggregate and makes the concrete impermeable. It provides strength to concrete by binding the aggregate into a solid mass due to its setting and hardening properties when mixed with water. Although, it constitutes only about 20% of the total volume of concrete mix, its contribution to the compressive strength of concrete is the maximum. A good quality cement should satisfy all the requirements as per I.S. specifications. The amount of cement required for a given mix should be in a range of minimum and maximum amount for the given grade as per the IS code provision.

Portland cement, also referred to as Ordinary Portland Cement (OPC), is the most important type of cement and is a fine powder produced by grinding Portland cement clinker. OPC is

classified into 3 grades namely 33 Grade, 43 Grade, 53 Grade depending upon the strength of 28 days. The specification for the cement of any grade is given by the various IS codes. IS 8112: 2013 provides the specification of the OPC 43 Grade.

Ordinary Portland Cement (OPC) of 43 Grade (Aditya Birla) from a single lot was used throughout the course of the investigation. It was fresh and without any lumps. The physical properties of the cement are determined from various method of physical test for cement (IS 4031) and the requirement, conforming to IS 8112:2013, are listed in Table 3.1. Cement was carefully stored to prevent deterioration in its properties due to contact with the moisture.

Table 3.1 Properties of OPC 43 Grade Cement

Characteristics	Values Obtained Experimentally	Value Specified by IS 8112:2013	Method of Test Ref.
Specific Gravity	3.12	-	IS 4031 part 11
Standard Consistency (percent)	27		IS 4031 part 4
Initial Setting Time (minutes)	165	30 (minimum)	IS 4031 part 5
Final Setting Time (minutes)	315	600(maximum)	IS 4031 part 5
Compressive Strength			IS 4031 part 6
3 days	24.9	23 N/mm ² (minimum)	
7 days	37.2	33 N/mm ² (minimum)	
28 days	49.5	43 N/mm ² (minimum)	

3.2.2 Aggregates

Aggregate occupy a large volume in concrete mixture and give dimensional stability to concrete. In the cement concrete, to provide good quality of concrete, aggregates are generally used in two size groups: coarse aggregates – Particle size more than 4.75mm and fine aggregate (sand) particle size less than 4.75mm. Coarse aggregates makes solid and hard mass of concrete with cement and sand and increase the crushing strength of concrete. It also reduce the cost of concrete, since it occupies major volume. Sand consists of small angular or rounded grains of silica and is commonly used as the fine aggregate in cement

concrete. It fills the voids existing in the coarse aggregate and reduces shrinkage and cracking of concrete. It helps in hardening of cement by allowing the water through its voids. To form hard mass of silicates, as it is believed that, some chemical reaction takes place between silica of sand and constituents of cement. The fine aggregate assist the cement paste to hold the coarse particle in suspension this action promotes plasticity in the mixture and prevent the possible segregation of paste and coarse aggregate. The aggregates, which provide about 75% volume to concrete, should meet certain requirement if the concrete is to be workable, strong, durable and economical. The aggregate must be proper in shape, clean hard and well graded.

Coarse aggregates: The aggregates which are retained over IS sieve 4.75mm are termed as coarse aggregate. The coarse aggregate may be of following types: Crushed gravels or stone obtained by crushing of gravel or hard stone and partially crushed gravel or stone obtained as a product of blending of above two types. The normal maximum size is 10mm to 20mm, however, particle sizes up to 40mm are also used in dry lean concrete. Regarding the characteristics of different type of aggregates, crushed aggregates tend to improve the strength because of interlocking of angular particles, whereas, rounded aggregates improve the workability due to the lower internal friction.

The coarse aggregate used in the present study were a mixture of two locally available crushed stones of 20mm and 10mm sizes. The aggregates were washed to remove dirt, dust and then dried to surface dry condition.

Specific gravity and other physical properties of coarse aggregates are provided in Table 3.2. The sieve analysis of coarse aggregate was done in the laboratory and the values obtained are shown in the Table 3.3 for the 20mm aggregate and Table 3.4 for the 10mm aggregate.

Table 3.2 Properties of Coarse Aggregates

Characteristics	Value	
Colour	Grey	
Shape	Angular	
Maximum size	20mm	10mm
Specific Gravity	2.71	2.75
Water Absorption	0.3%	0.5%

Table 3.3 Sieve Analysis of Coarse Aggregates (20mm)

S.No.	IS-Sieve (mm)	Wt. Retained (gm)	%age Retained	%age passing	Cumulative % retained
1	80	0.00	0.00	100.00	0.00
2	40	0.00	0.00	100.00	0.00
3	20	28	0.93	99.07	0.93
4	10	2876	95.87	3.20	96.8
5	4.75	75	3.20	0	99.3
6	2.36	0	0	0	100
7	1.18	0	0	0	100
8	600	0	0	0	100
9	300	0	0	0	100
10	150	0	0	0	100
11	Pan	21	0.7		
Total		3000		SUM	697.03
Fineness Modulus (FM) = 6.97					

Table 3.4 Sieve Analysis of Coarse Aggregate (10mm)

S.No.	IS-Sieve (mm)	Wt. Retained (gm)	%age Retained	%age passing	Cumulative % retained
1	80	0.00	0.00	100.00	0.00
2	40	0.00	0.00	100.00	0.00
3	20	447	22.35	77.65	22.35
4	10	415	20.75	56.90	43.1
5	4.75	1055	52.75	4.15	95.85
6	2.36	80	4.0	0.15	99.85
7	1.18	0	0	0	100
8	600	0	0	0	100
9	300	0	0	0	100
10	150	0	0	0	100
11	Pan	3	0.15		
Total		2000		SUM	661
Fineness Modulus (FM)= 6.61					

Fine aggregates: The aggregates, most of which pass through 4.75mm IS sieve are termed as fine aggregates. The fine aggregates may be of following types: Natural sand, i.e. the fine aggregate resulting from natural disintegration of rocks, Crushed stone sand, i.e. the fine aggregate produced by crushing hard stone, Crushed gravel sand, i.e. the fine aggregate produced by crushing natural gravel. Depending upon the particle size distribution IS 383

has divided the fine aggregate into four grading zones (Grade I to IV). The grading zones become progressively finer from grading zone I to IV. In this experiment program fine aggregates were collected from the local supplier and were conforming to grading zone II. It was free from silt and clay particles. Sieve analysis and physical properties of fine aggregates are tested as per IS: 383 and result are shown in the Table 3.5. Specific gravity of fine aggregates was experimentally determined as 2.55.

Table 3.5 Sieve Analysis of Fine Aggregate

S.No.	IS-Sieve (mm)	Wt. Retained (gm)	%age Retained	%age passing	Cumulative retained %
1	4.75	5	0.5	99.5	0.5
2	2.36	59	5.9	93.6	6.4
3	1.18	136	13.6	80	20.0
4	600 μ	243	24.30	55.7	44.3
5	300 μ	415	41.5	14.2	85.8
6	150 μ	122	12.2	2	98.0
7	Pan	20	2	SUM	255.0
TOTAL		1000	Zone II		FM =2.55

3.2.3 Marble dust

Marble dust was collected from AshokaMarbles, ITI Chowk, Bathinda. It was white in colour and air dried and was packed in bags in powder form as shown in Fig 3.1a. It was sieved through 4.75 mm and other lower sieves so as to find out its Fineness Modulus. Table 3.6 shows the sieve analysis for marble dust. The fineness modulus of the marble dust came out to be 1.27.

3.2.4 Furnace Slag

Furnace slag was collected from Singla industry, Amloh road, MandiGobindgarh. It was the dust collected during the cutting of large slabs pieces into coarse aggregate as shown in the Fig 3.1b. It was brown in colour and was obtained as a waste product from the furnace industry. It was sieved through 4.75mm and other lower sieves so as to find the fineness modulus. The sieve analysis results are shown in the Table 3.7. The fineness modulus of the furnace slag came out to be 1.76.

Table 3.6 Sieve Analysis of Marble Dust

Weight of sample taken = 100 gm					
S.No.	IS-Sieve (mm)	Wt. Retained (gm)	%age Retained	%age passing	Cumulative % retained
1	4.75	0	0	100	0
2	2.36	0	0	100	0
3	1.18	0	0	100	0
4	600 μ	8	8	92	8
5	300 μ	11	11	81	19
6	150 μ	81	81	0	100
7	Pan	0	0	SUM = 127	
Fineness Modulus (FM) = 1.27					

Table 3.7 Sieve Analysis of Furnace Slag

Weight of sample taken =					
S.No.	IS-Sieve (mm)	Wt. Retained (gm)	%age Retained	%age passing	Cumulative % retained
1	4.75	4	0.4	99.6	0.4
2	2.36	60	6.0	93.2	6.4
3	1.18	78	7.8	85.4	14.2
4	600 μ	120	12.0	73.4	26.2
5	300 μ	212	21.2	52.2	47.4
6	150 μ	345	34.5	17.7	81.9
7	Pan	181		SUM	176.5
Fineness Modulus (FM) = 1.76					

X-ray diffraction analysis for furnace slag: X-ray powder diffraction (XRD) is a rapid analytical technique primarily used for phase identification of a crystalline material and can provide information on unit cell dimensions. The analyzed material is finely ground, homogenized, and average bulk composition is determined. By comparing the positions and intensities of the diffraction peaks against a library of known crystalline materials, the target material can be recognized. In addition, multiple phases in a sample can be identified

and quantified. X-ray diffraction (XRD) data for grind sample was tested on Panalytical's X'Pert Pro with Cu K α radiation at SAI lab of Thapar University. The sample was scanned in the range of $2\theta = 10-90^\circ$. Fig 3.2 represents the main peaks for the different compounds present in the furnace slag.



Fig 3.1a Marble Dust Used For Experimental Work



Fig 3.1b Furnace Slag Production in Industry

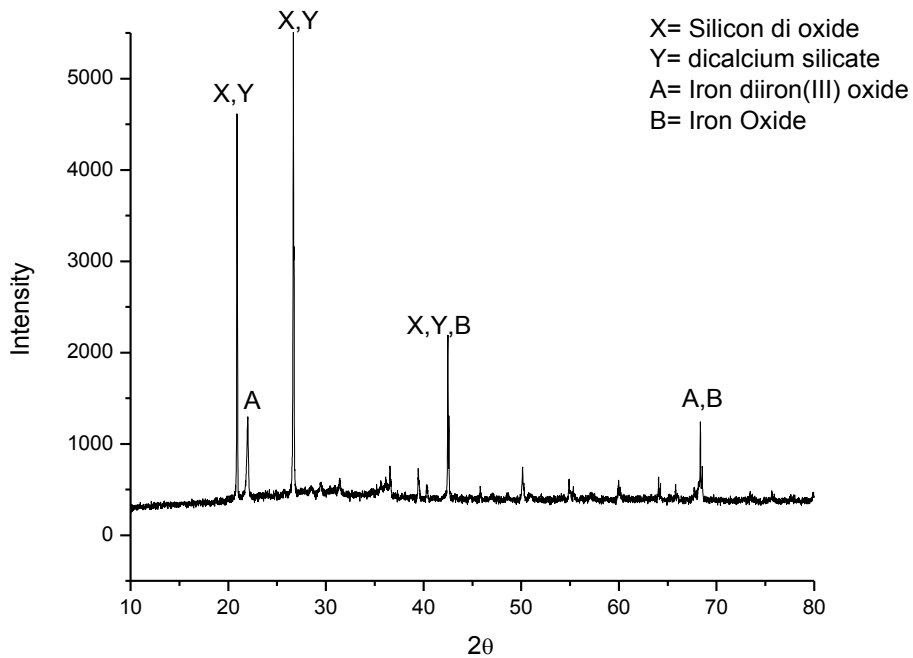


Fig 3.2 X-Ray Diffraction of Iron Furnace Slag

3.2.5 Water

The potable water is generally considered satisfactory for mixing and curing of concrete. Accordingly potable water was used for making concrete available in material testing laboratory. It was free from any detrimental contaminants and was of good potable quality.

3.2.6 Super plasticizer

Conplast® SP430 procured from FOSROC Constructive Solutions was used in the present study. Conplast SP430 complies with IS: 9103:1999 and BS: 5075 Part 3. Conplast SP430 is based on Sulphonated Napthalene Polymers and supplied as a brown liquid instantly dispersible in water. Conplast SP430 has been specially formulated to give high water reductions up to 25% without loss of workability or to produce high quality concrete of reduced permeability. Table 3.8 shows the characteristics of Conplast SP430.

The dosage of super plasticizer recommended is 0.6% to 2% by weight of cementitious material. In this study, to attain medium workability of the control mix, super plasticizer amount of 0.6% of cement content was used, and for the other mix the quantity of super

plasticizers were found out depending upon the trials for achieving medium range of workability.

Table 3.8 properties of super plasticizer

S.No.	Characteristics	Value
1	Type	Sulphonated Napthalene Polymers
2	Form	Liquid
3	Colour	Light brown
4	Specific gravity	1.220 to 1.225 at 30°C
5	Air Entrainment	Approx. 1% additional air is entrained

3.3 MIX DESIGN OF PAVEMENT QUALITY CONCRETE (PQC)

IRC 44: 2008 was followed for the mix design of pavement quality concrete, and the materials used confirmed to the various clauses of MORTH specifications. The cement concrete pavements were designed on the basis of flexural strength requirement of concrete. However, general practice is to design the mix on cube compressive strength and relationship between characteristic compressive strength and flexural strength as per IS: 456 was used as follow:

Flexural strength, (N/mm²) = 0.7 times the characteristic compressive cube strength of concrete, (N/mm²).

3.3.1 Design Parameters

Characteristic flexural strength required at 28 days	4.5 N/mm ²
Maximum water cement ratio=	0.50
Maximum size of aggregate =	25mm
Degree of quality control =	Good
Minimum cement content =	350 kg/m ³
Maximum cement content=	425 kg/m ³
As per clause 602 of MORTH specification:	
Cement	43 Grade OPC as per IS 8112
Coarse aggregate	20mm and 10mm as per 602.2.4
Fine aggregate	Sand as per IS 383 of zone II

3.3.2 Step involved in the mix design as per IRC 44

1. *Determinations of target strength* = 4.5 N/mm² (Grade designation M40)
Target mean strength = 40 + 1.65 * 5 = 48.25 N/mm²
2. *Selection of water – cement ratio*: from the table 4 of IRC: 44-2008 approx. W/C ratio for M40 is 0.38. Assume w/c 0.4 < 0.50 OK.
Table 5 of IRC: 44 used for the suggestive water content for 20mm maximum size of aggregates and that is 186 kg/m³, reduction for water content up to 20% was done by use of super plasticizer and the water content used was 154 kg/m³.
3. *Calculation of cement content*: Water-cement ratio = 0.40 and water content = 154 kg/m³ thus cement content = 154/0.40 = 385 kg/m³ which was within the prescribed minimum and maximum limits.
4. *Determination of the proportion of aggregates*: From the table 6 of IRC: 44 for w/c of 0.50 and 20mm maximum size the volume of coarse aggregate per unit volume of total aggregate for Zone II of fine sand is 0.62. For every decrease of 0.05 in w/c ratio, the given ratio will be increased approximately by 1 per cent. Thus for w/c ratio of 0.40 the ratio for coarse aggregate was calculated as 0.64 (coarse) and 0.36 (fine).
5. *Combination of different coarse aggregate fractions*: In coarse aggregate 20mm and 10mm size of aggregate were used and for the suitable proportion so as to result in an overall grading conforming to table 1 of IRC: 44 they were used in ratio 60 by 40 i.e. 60% of 20mm aggregates and 40% of the 10mm size aggregates. Thus, the percentage of 20mm sized aggregate was 38.4 and for the 10 mm size aggregate 25.6 percent of total fraction of coarse aggregate.

For calculation of total quantity of various composition of the concrete in kg per unit volume the relation used was follow:

$$V = \left[W + \frac{C}{S_c} + \frac{1}{\phi} \times \frac{fa}{S_{ca}} \right] \times \frac{1}{1000}$$

Where V is the absolute volume of the wet mix, W is the mass of water in kg per cum of concrete, C is the mass of cement in kg per cum of concrete, S_c is the specific gravity of cement, ϕ is the proportion (in decimal fraction) of aggregate (20mm, 10mm, sand) and S_{ca} is the respective specific gravity. fa is mass of the aggregate in kg per cum of concrete.

Thus the quantity of aggregates was calculated by simply putting the value of their fractions and specific gravity in the equation and the value of fa was obtained. Table 3.9 shows the quantities of material per unit volume of the concrete assuming that there was 2% air in the

1 cum concrete. For the control mix superplasticizer quantity of 0.6% by weight of cement was used.

Table 3.9 Proportion for Pavement Quality Concrete Mixture (control mix)

	Water	Cement	F.A. (sand)	C.A. (20mm)	C.A. (10mm)
Quantity (kg/m³)	154	385	653.5	732	495
Proportion(wt)	0.4	1	1.69	1.90	1.28

Various concrete mixes were prepared with the varying percentage of marble dust and furnace slag in the laboratory. Table 3.10 shows the quantity of material in kg/m³ for different mixes which were prepared in the laboratory.

Table 3.10 Quantity of Material (in kg/m³) for different Mixes

Mix	Water	Super plasticizer	Cement	Fine aggregates			C.A. (20mm)	C.A. (10mm)
				Sand	FS	MD		
M1	154	2.32	385	620.3	0	32.67	732	495
M2	154	2.70	385	588.2	0	65.3	732	495
M3	154	2.90	385	555.5	0	98	732	495
M4	154	3.08	385	588.2	65.3	0	732	495
M5	154	3.46	385	522.8	130.6	0	732	495
M6	154	4.82	385	457.5	196	0	732	495
M7	154	3.85	385	555.5	65.3	32.67	732	495
M8	154	4.82	385	490.1	130.6	32.67	732	495
M9	154	5.80	385	424.8	196	32.67	732	495
M10	154	4.23	385	522.8	65.3	65.3	732	495
M11	154	5.00	385	457.5	130.6	65.3	732	495
M12	154	6.16	385	392.2	196	65.3	732	495
M13	154	4.82	385	490.1	65.3	98	732	495
M14	154	6.70	385	424.9	130.6	98	732	495
M15	154	7.70	385	359.5	196	98	731	495

3.5 MAKING AND CURING OF TEST SPECIMENS IN LABORATORY

The quantities of cement, each size of aggregate, and water for each batch were determined by weight and the concrete ingredients were mixed in a laboratory mixer. When the mixing drum is charged by a power loader, all the mixing water should be introduced into the drum before the solid material. Subsequently, half the coarse aggregates were loaded, then the fine aggregates, then cement and finally the remaining coarse aggregates are loaded in the mixer. If admixture is used, it is diluted with some water and sprinkled at the last in the mix when the entire ingredients are loaded in the mixer. The period of mixing should be not less than 2 minutes after all the materials are in the drum, and had to continue till the resulting concrete is uniform in appearance. The entire procedure as laid down above was diligently followed for preparation of all the concrete mixes.

Each batch of concrete was tested for consistency immediately after mixing by the slump test as described in IS: 1199:1959. The slump for the mix was in range of 50 to 75mm. The mould for test specimen conforming to IS: 10086-1982 were used for casting of cubes and beams, as per laid down specifications for moulds to be used in tests of cement and concrete. Compression test specimen were cubical sized with dimensions of 15×15×15 cm and for flexural test beam specimens were of the size of 15×15×70 cm.

The test sample was made as soon as practicable after mixing and in such a way as to produce full compaction of the concrete with neither segregation nor excessive laitance. Table vibrator was used for compaction of concrete in the mould. The test specimens were stored in a place, free from vibration, in moist air of at least 90 % relative humidity, and at a temperature of $27 \pm 2^{\circ}\text{C}$ for 24 hours. After this period, the specimen were marked and removed from the mould and then stored in clean water until the time of test. The test sample were cured in the curing tank which is available in laboratory. At the time of test the samples were tested immediately on removal from the water, when they were still in the wet condition. The samples were tested after a curing period of 7, 28 and 56 days for compressive strength and 7 and 28 days for flexural strength.

4.1 GENERAL

This chapter deals with the observation of the results from the various tests conducted on concrete for use as pavement quality concrete. The results are compared with the control concrete mixes for the various percentage replacement levels of sand with marble dust and furnace slag. The strength characteristics of concrete containing marble dust and furnace slag are discussed in this chapter. Tests were performed on hard concrete cured under standard laboratory conditions, and compressive and flexural strengths were observed at curing ages of 7, 28, 56 days.

4.2 COMPRESSIVE STRENGTH OF CONCRETE

4.2.1 General

The main function of the concrete in structure is mainly to resist the compressive forces. When a plain concrete member is subjected to compression, the failure of the member takes place, in its vertical plane along the diagonal. The vertical cracks occur due to lateral tensile strain. A flow in the concrete, which is in the form of micro crack along the vertical axis of the member will take place on the application of axial compression load and propagate further due to the lateral tensile strain.

4.2.2 Test procedure and results for compressive strength

Test specimens of size 150×150×150 mm were prepared for testing the compressive strength of both controlled as well as marble dust and furnace slag based concretes. The modified mixture with varying percentage of furnace slag and marble dust as a partial replacement of sand were prepared and cast into cubes. Compressive strength test results at curing ages of 7, 28, and 56 days for control mix as well as for the modified mixes are shown in the Table 4.1. For testing in compression, no cushioning material was placed between the specimen and the plates of the machine. The load was applied axially without shock till the specimen was crushed. Fig 4.1 shows the test setup for the compressive strength.

Three specimens for each mix were tested and the corresponding values were observed and average value were taken for discussion. Fig 4.2 shows the variation of compressive

strength with varying percentage replacement of sand with marble dust, whereas, the Fig 4.3 shows the variation at different curing ages for varying percentage replacement levels of sand with iron slag.

Figs 4.4 to 4.6 shows the variations with both materials being used as replacements of sand in the concrete.

Table 4.1 Compressive Strength Test Result

Mix Designation	Concrete mix		7 days	28 days	56 days
<i>CM</i>	<i>Control mix</i>		35.2	52.6	55.6
M1	FS 0%	MD 5%	36.1	53.9	56.1
M2	0%	10%	38.5	58.2	60.8
M3	0%	15%	35.7	60.7	62.4
M4	FS 10%	MD 0%	34.2	55.4	60.2
M5	20%	0%	33.4	57.6	63
M6	30%	0%	31.2	54.4	60.3
M7	FS 10%	MD 5%	36.4	59.7	64.4
M8	20%	5%	35.1	60.9	66.9
M9	30%	5%	33	54.2	62.4
M10	FS 10%	MD 10%	37.3	60.5	66.2
M11	20%	10%	35.4	57.2	61.8
M12	30%	10%	34.6	48.8	55.9
M13	FS 10%	MD 15%	38.2	61	65.8
M14	20%	15%	37.5	51.4	54.4
M15	30%	15%	35.7	47.5	51.2



Fig 4.1 Compressive strength test setup

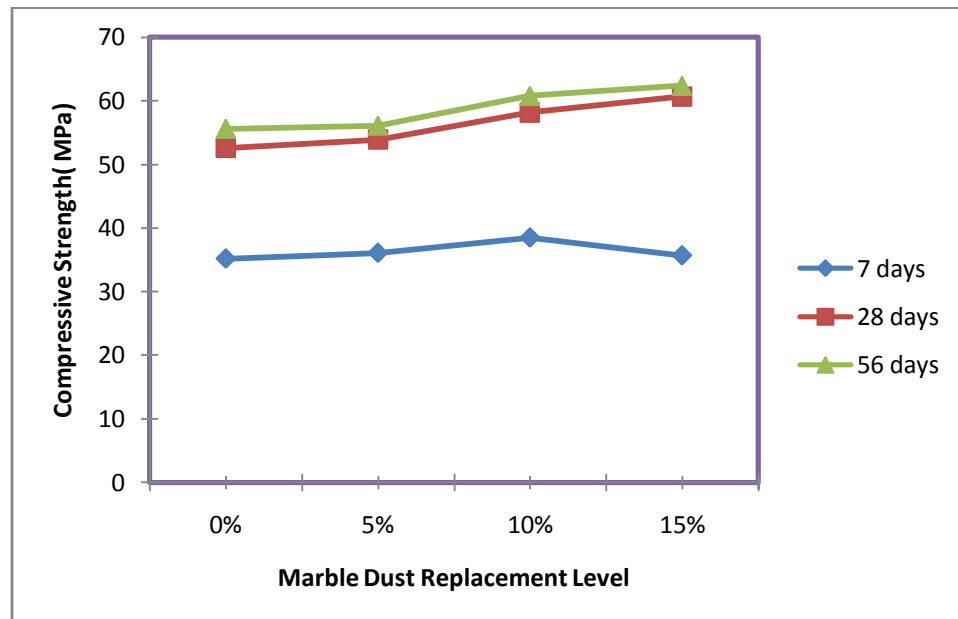


Fig 4.2 Variation of compressive strength of concrete with different % replacement levels of marble dust at different curing ages

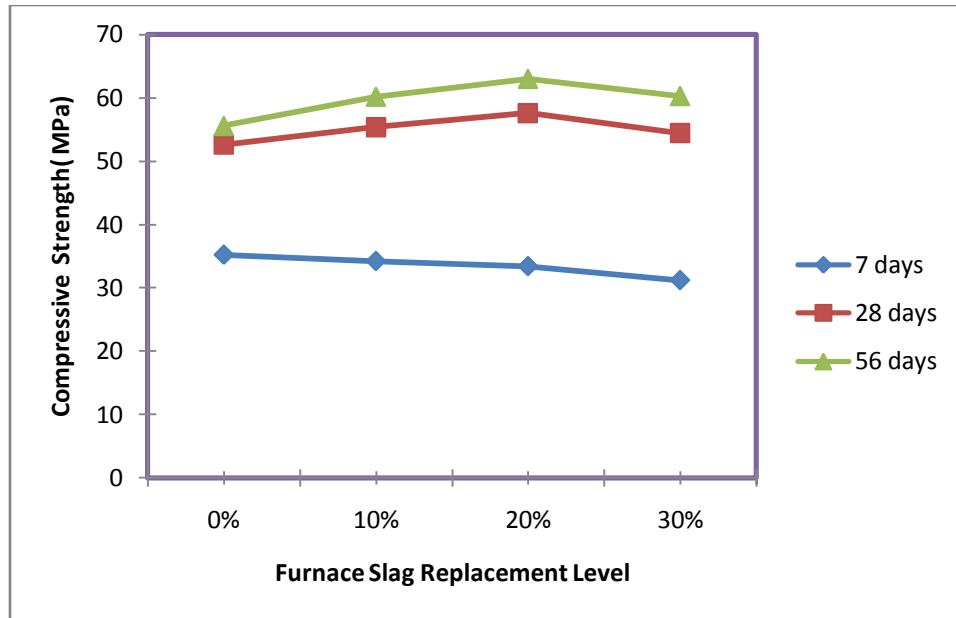


Fig 4.3 Variation of compressive strength of concrete with different % replacement levels of furnace slag at different curing ages

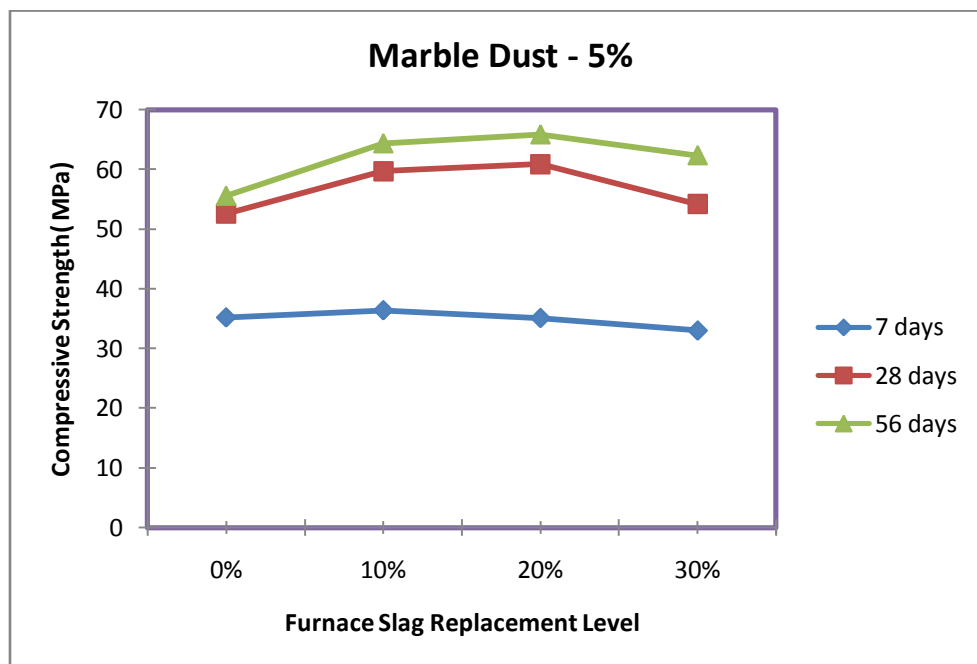


Fig 4.4 Variation of compressive strength of concrete with different % replacement levels of furnace slag for 5% MD at different curing ages

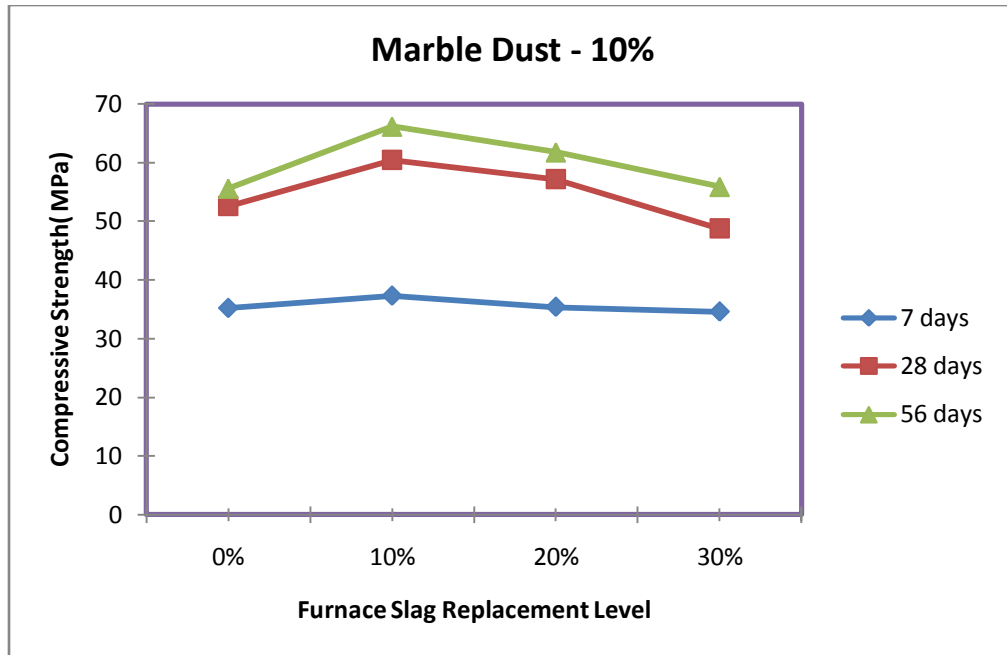


Fig 4.5 Variation of compressive strength of concrete with different % replacement levels of furnace slag for 10% MD at different curing ages

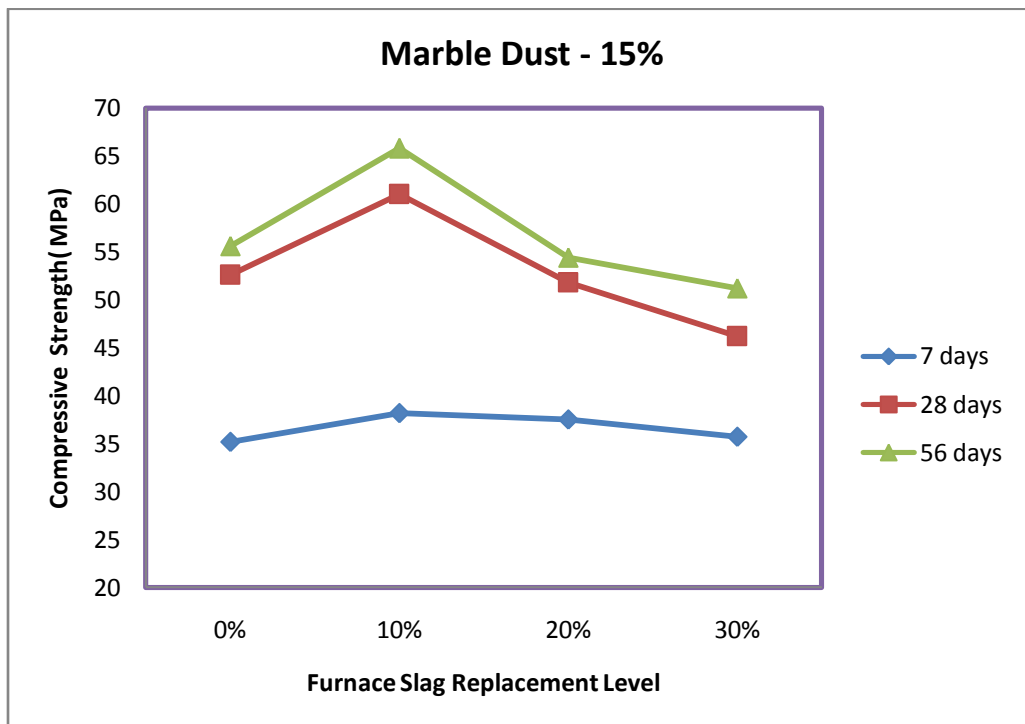


Fig 4.6 Variation of compressive strength of concrete with different % replacement levels of furnace slag for 15% MD at different curing ages

4.2.3 Discussion of results

The Table 4.1 and figures 4.2 to 4.6 show the effect of replacement of sand with marble dust and furnace slag on the compressive strength behavior of concrete. From the Fig. 4.2, which shows the effect of replacement of sand only with MD, it was observed that the compressive strength of concrete increased as the percentage replacement level of MD was increased, for all ages. On the other hand, for mixes containing only furnace slag (Fig. 4.3), it was observed that at early age of 7 days, there was a decrease in the compressive strength of concrete as the percentage of furnace slag was increases in the mix. However, at the later curing ages of 28 and 56 days, the compressive strength increased up to 20% replacement and then subsequently decreased. This indicates that furnace slag, being a pozzolanic material, resulted in less early age strength, but there was a gain in later age strengths due to the pozzolanic reaction which sets in late.

It can also be observed from Table 4.1 that all the mixes containing only marble dust could achieve higher than the designated strength of the control mix at all ages, whereas the mixes containing only furnace slag could not achieve the control mix strength at 7 days, but the strength was higher for all levels at 28 and 56 days, as compared to both the control mix as well as mixes containing only marble dust. This indicates that furnace slag can be used as an ideal replacement for sand if later ages strengths are a priority, whereas marble dust would serve well for mixes where early age strength is the need.

The table 4.1 and Figs. 4.4 to 4.6 show the variation in compressive strength of concrete mixes cast using both marble dust and furnace slag, in varying proportions, as replacement of sand or fine aggregates.

It can be observed form the above mentioned table and figures that by keeping a fixed percentage of marble dust and varying the percentage level of furnace slag in the mix, there was a slight increase which was observed at 10% level of furnace slag at 7 days, but subsequently at higher levels of 20% and 30% the strength decreased. This indicates that at early ages, even though marble dust was used in higher quantity, the furnace slag variation dictated the effect on the compressive strength of concrete at early ages.

At both 28 and 56 days, it was observed that for 5% marble dust level, the compressive strength increased, although marginally, for 10% and 20% levels of furnace slag, and then there was a subsequent decrease in the compressive strength. On the other hand for 10% fixed marble dust content, for both 28 and 56 days curing ages, the compressive strength increased up to 10% level of furnace slag replacement, and then gradually decreased for

20% and 30% replacement levels. A similar trend was observed for a fixed marble dust content of 15% at both curing ages, with a change that the strength decrease was significantly more at the 20% furnace slag replacement level as compared to the 10% level. These observations indicate that the optimum replacement level of sand with both the materials, marble dust and furnace slag used in combination was 20 to 25% only.

The highest early age strength, 7 days, could be achieved by using only 10% marble dust as sand replacement indicating that marble dust replacement helps in early age strength development.

The highest strength in compression at 28 days could be achieved by using a combination of the two materials either 10% furnace slag or 15% marble dust or 20% furnace slag and 5% marble dust. This indicates that the pozzolanic reaction of furnace slag helped in gaining strength from a period of 7 to 28 days. Highest strength at 56 days for a combination of 20% furnace slag and 5% marble dust further corroborates the point made earlier.

Fig 4.7 shows the percentage variation in compressive strength as compared to the control mix, for all the mixes after 7 days curing.

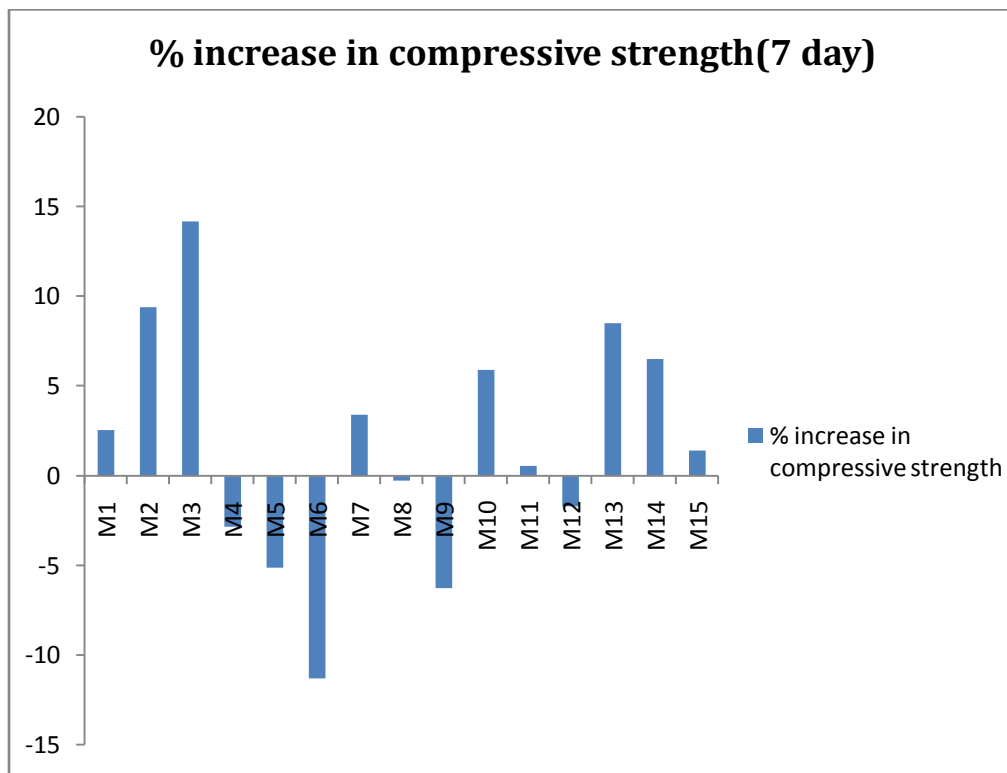


Fig 4.7 Percentage variation in compressive strength of various mixes as compared to the normal mix at 7 days

It can be observed from the figure 4.7 that all the mixes containing only furnace slag or higher percentages of furnace slag when used in combination with marble dust could not achieve the control mix strength, reinforcing the point that use of furnace slag was not suitable for early age strength gain. The increase in the strength for all mixes containing marble dust was due to the cementitious property of marble dust which was developed by hydration of calcite and C₃A chemically, and also it acted as a filler material in the mix which decreased the porosity of the concrete mix.

For the furnace slag the decrease in the strength may be due to increase in demand for the cement in the mix. This happens as the furnace slag has a large surface area than the sand. As the surface area increased the demand for cement also increased, which though remained same for all the mixed, resulting in a decreased strength. The variation of the decrease in strength increased if we increased the furnace slag percentage in the mix.

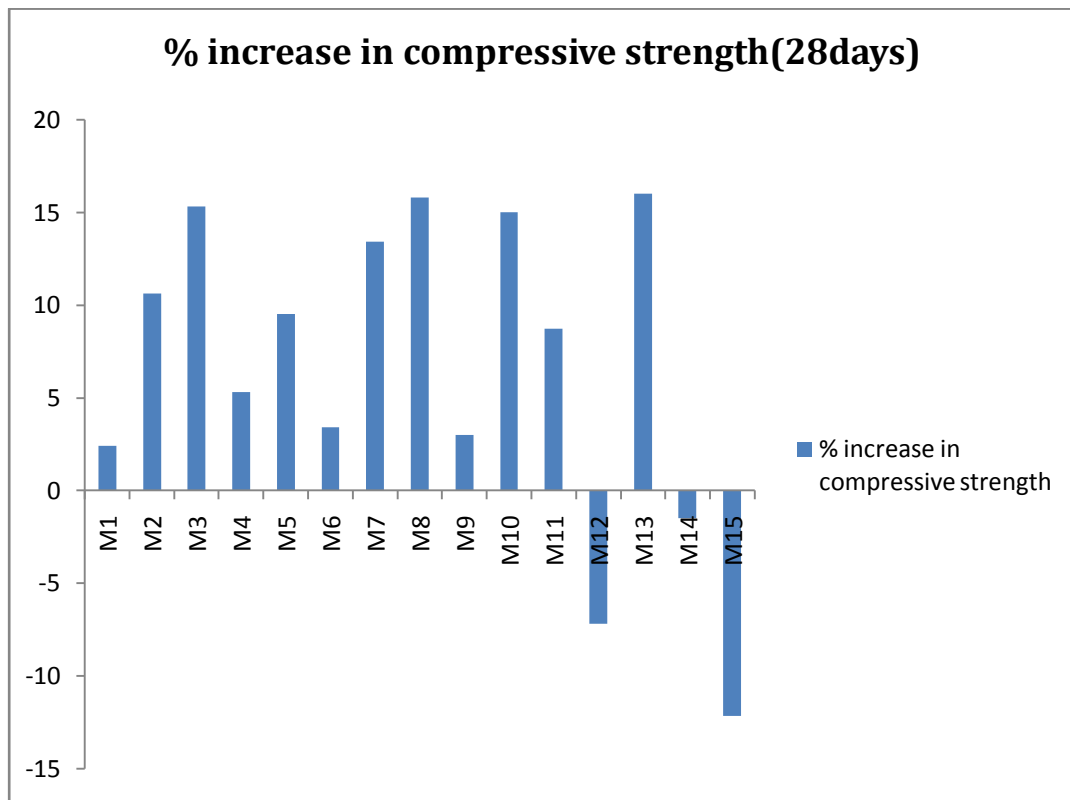


Fig 4.8 Percentage variation in compressive strength of various mixes as compared to the normal mix at 28 days

Fig 4.8 shows the percentage variation in compressive strength as compared to the control mix, for all the mixes after 28 days curing.

It can be observed from the figure 4.8 that all the mixes having a combined replacement content more than 30% could not achieve the strength of control mix itself, in fact the percentage decrease was observed to be in the range of 8 to 12%. For most of the other mixes, individually or in combination a maximum increase of 15% was observed. This increase in compressive strength was due to the hydraulic reaction of the slag with available calcium hydroxide (CH) and alkalis to form an additional C-S-H.

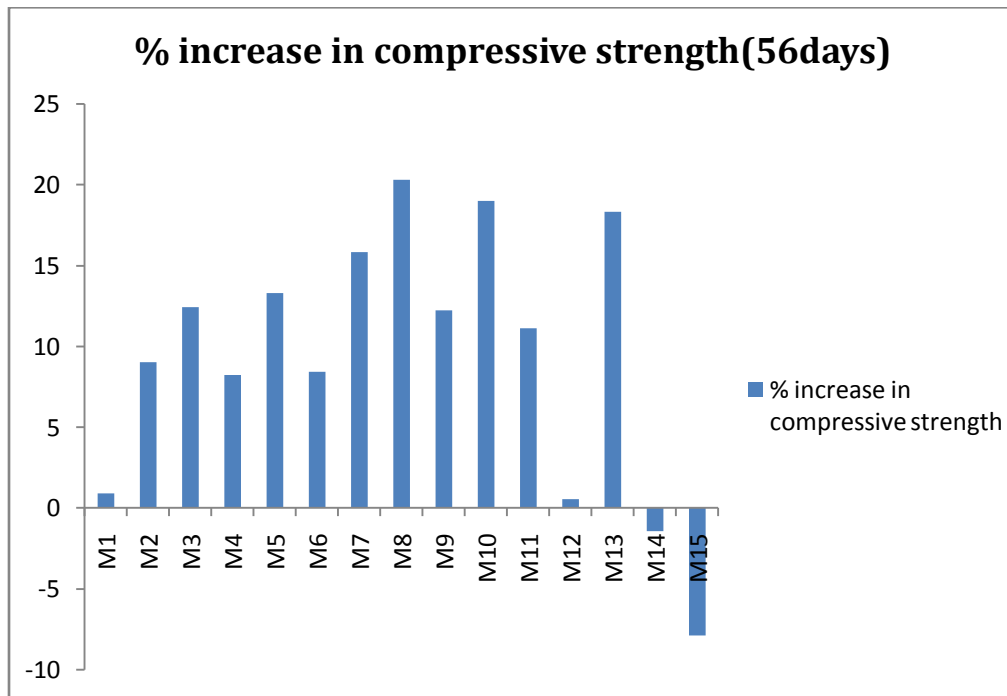


Fig 4.9 Percentage variation in compressive strength of various mixes as compared to the normal mix at 56 days

Fig 4.9 shows the percentage variation in compressive strength as compared to the control mix, for all the mixes after 56 days curing. A trend very similar to the 28 days strength was observed at 56 days as well. All the mixes having more than 30 to 35% combined percentage replacement could either just achieve the control mix strength or had lesser strength, although the percentage reduction was of the order of 4 to 8% only. For most of the other mixes, individually or in combination a maximum increase of 20 to 22% was observed. This reinforces our earlier conclusion that optimum replacement of furnace slag in combination with marble dust could help achieve higher later age strengths.

4.2 FLEXURAL STRENGTH OF CONCRETE

4.2.1 General

Most of the concrete, which is used in highway or airport pavements, is subjected to flexure and is evaluated by applying bending tests. As the flexural strength of concrete has a direct relation with the thickness of the slab its evaluation becomes the most important component of pavement design. When concrete is subjected to bending, then tensile and compressive stresses and in many cases direct shear stresses are also developed. The deflection and cracking behavior of concrete structure to a large extent depends upon the flexural tensile strength of concrete. Many factors have been shown to influence the flexural tensile strength of concrete, particularly the level of stress, size, age and confinement to concrete flexure member.

4.3.2 Test procedure and results for flexural strength

The flexural test beam specimens of size of 15×15×70 cm were cast and cured for 7 and 28 days under standard laboratory conditions. For testing the specimens were placed in the machine in such a manner that the load was applied to the uppermost surface as cast in the mould, along two lines spaced 20cm apart. The axis of the specimen was carefully aligned with the axis of the loading device. No packing material was used between the bearing surface of the specimen and the rollers. The load was applied at a rate of loading of 400kg/min, and was applied until the specimen failed, and the maximum load applied to the specimen during the test was recorded for the further analysis. The flexural strength of the specimen is expressed as the modulus of rupture f_b , if the fracture occurred within the central one-third of the beam; the flexural strength was calculated on the basis of ordinary elastic theory using the following equation:

$$f_b = \frac{p \times l}{b \times d^2}$$

Where f_b is the flexural strength, p is the maximum load applied to the specimen, b is measured width of the specimen, d is the depth of the specimen at the point of failure, and l is the length of the span on which the specimen was supported. Third point loading condition was used for the test procedure in which the two points loading is applied to the beam 20cm apart. Fig 4.10 shows the third point condition and test setup for the flexural strength test.

Three specimens for each mix were tested and the corresponding values were observed and average value was taken for further discussion. Table 4.2 shows the values of flexural strength obtained for various mixes including the control mix.

Fig 4.11 shows the variation of flexural strength with varying percentage replacement of sand with marble dust only, whereas, the Fig 4.12 shows the variation at different curing ages for varying percentage replacement levels of sand with furnaceslag only.

Figs 4.13 to 4.15 shows the variations with both materials being used as replacement of sand in the concrete.

Table 4.2 Flexural strength test results

Mix Designation	Concrete mix		7 days	28 days
<i>CM</i>	<i>Control mix</i>		3.69	4.96
M1	FS 0%	MD 5%	3.79	5.15
M2	0%	10%	3.90	5.46
M3	0%	15%	3.95	5.55
M4	FS 10%	MD 0%	3.6	5.4
M5	20%	0%	3.49	5.59
M6	30%	0%	3.42	5.33
M7	FS 10%	MD 5%	3.72	5.64
M8	20%	5%	3.68	5.83
M9	30%	5%	3.58	5.47
M10	FS 10%	MD 10%	3.95	6.05
M11	20%	10%	3.81	5.72
M12	30%	10%	3.72	4.78
M13	FS 10%	MD 15%	4.02	5.22
M14	20%	15%	3.89	4.84
M15	30%	15%	3.80	4.55



Fig 4.10 Test setup for flexural strength

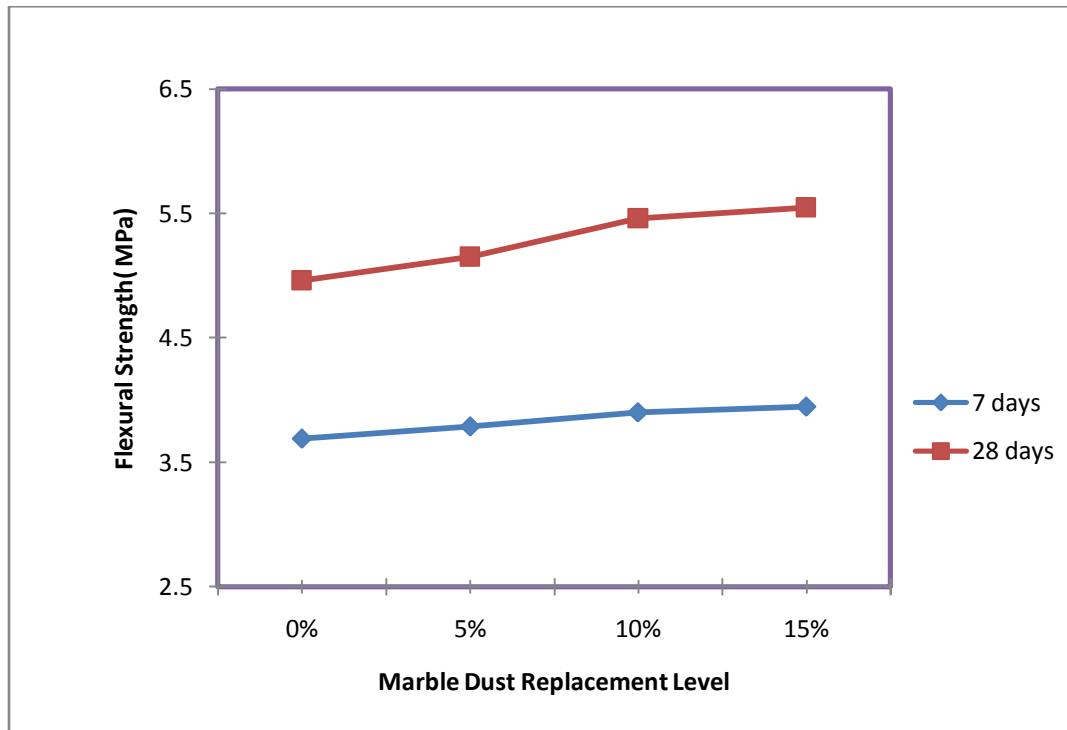


Fig 4.11 Variation of flexural strength of concrete with different % replacement levels of marble dust at different curing ages

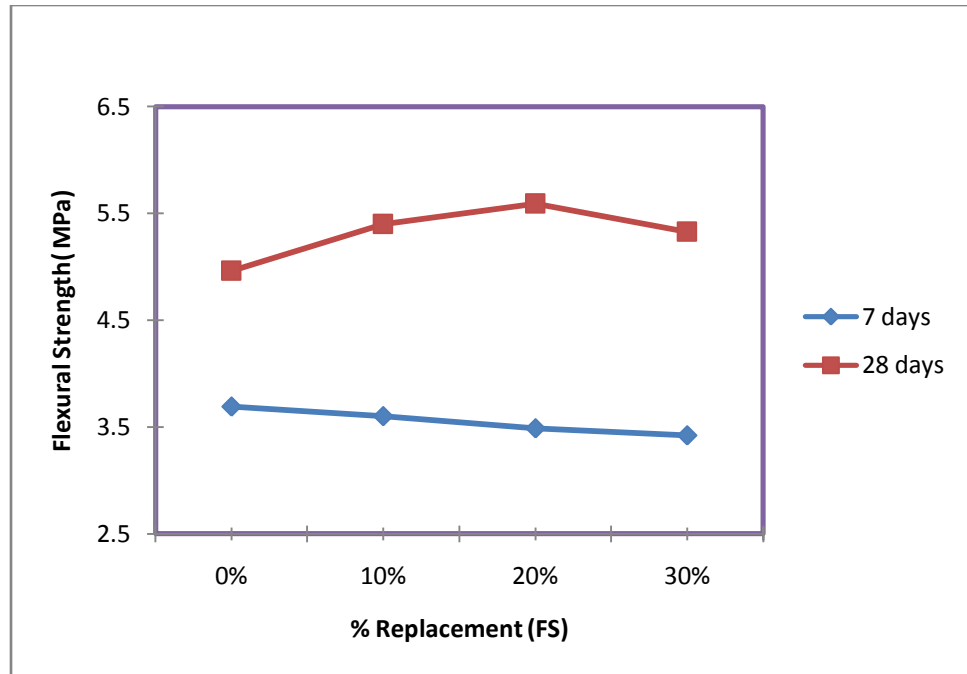


Fig 4.12 Variation of flexural strength of concrete with different % replacement levels of furnace slag at different curing ages

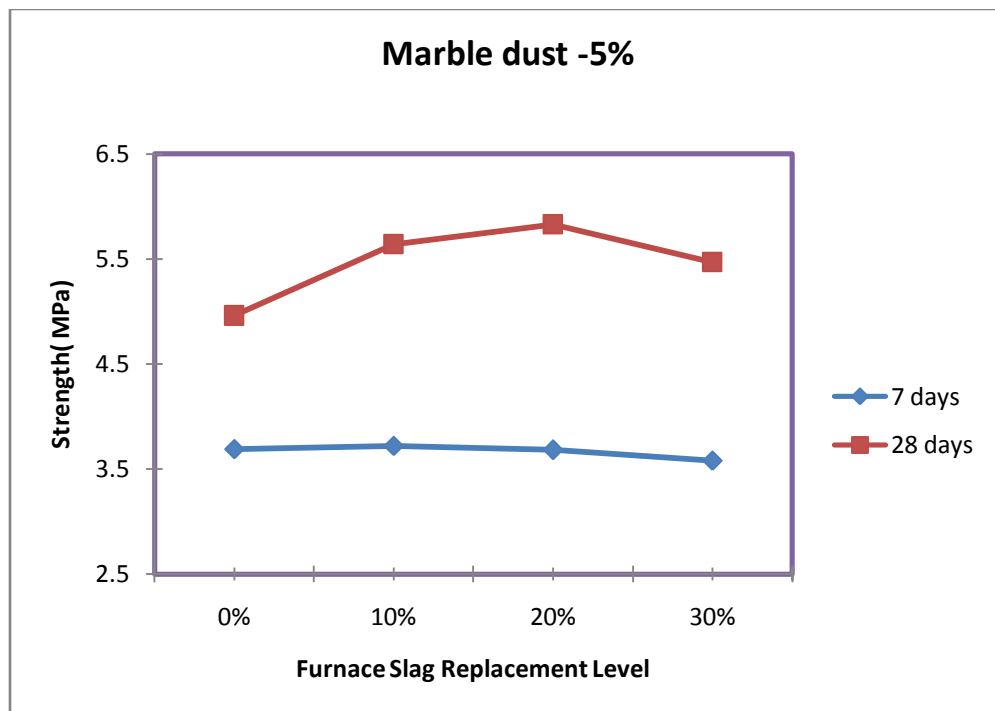


Fig 4.13 Variation of flexural strength of concrete with different % replacement levels of furnace slag for 5% MD at different curing ages

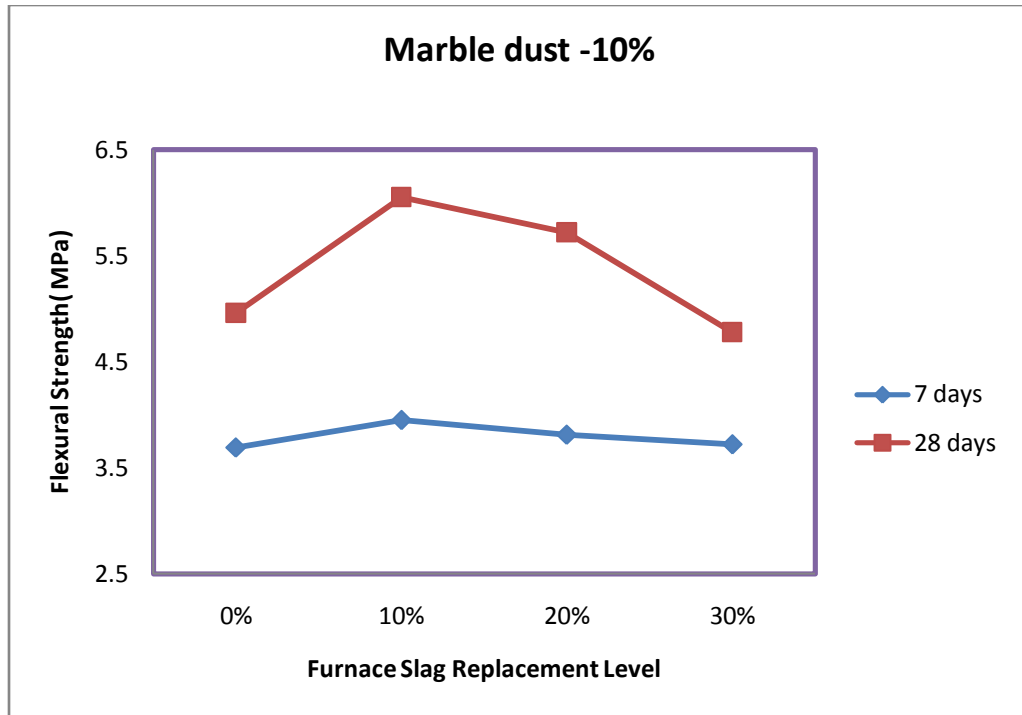


Fig 4.14 Variation of flexural strength of concrete with different % replacement levels of furnace slag for 10% MD at different curing ages

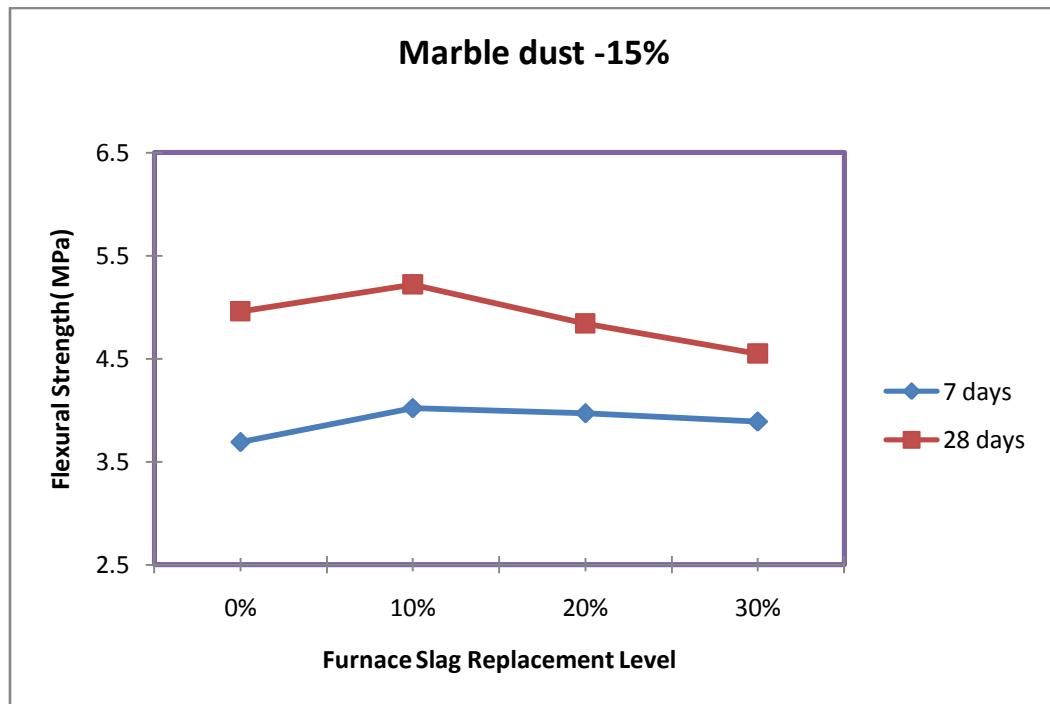


Fig 4.15 Variation of flexural strength of concrete with different % replacement levels of furnace slag for 15% MD at different curing ages

4.3.3 Discussion of results

The Table 4.2 and figures 4.11 to 4.15 show the effect of replacement of sand with marble dust and furnace slag on the flexural strength behavior of concrete. From the Fig. 4.11 which shows the effect of replacement of sand only with MD, it was observed that the flexural strength of concrete increased as the percentage replacement level of MD is increased, for all ages. On the other hand, for mixes containing only furnace slag (Fig. 4.12), it was observed that at early age of 7 days, there was a decrease in the flexural strength of concrete as the percentage of furnace slag was increased in the mix. A similar behavior was also observed for compressive strength results as well. However, at the curing age of 28 days, the flexural strength increased up to 20% replacement and then subsequently decreased. This indicates that furnace slag, being a pozzolanic material, results in less early age flexural strength, but there was a gain in later age strengths due to the pozzolanic reaction which sets in late.

It can also be observed from Table 4.2 that all the mixes containing only marble dust could achieve flexural strength higher than the designated value of the control mix at both ages, whereas the mixes containing only furnace slag could not achieve the control mix flexural strength at 7 days, however, the flexural strength was higher for all levels at 28 days, as compared to both the control mix as well as mixes containing only marble dust. This indicates that furnace slag can be used as an ideal replacement for sand if later age flexural strengths are a priority, whereas marble dust would serve well for mixes where early age strength is the need.

The Table 4.2 and Figs. 4.13 to 4.15 show the variation in flexural strength of concrete mixes cast using both marble dust and furnace slag, in varying proportions, as replacement of sand or fine aggregates.

It can be observed from the above mentioned table and figures that by keeping a fixed percentage of marble dust and varying the percentage level of furnace slag in the mix, there was a slight increase which was observed at 10% level of furnace slag at 7 days, but subsequently at higher levels of 20% and 30% the strength decreased. This indicates that at early ages, even though marble dust is used in higher quantity, the furnace slag variation dictates the effect on the flexural strength, on similar line as that on compressive strength, of concrete at early ages.

At 28 days curing, it was observed that for 5% marble dust level, the flexural strength increased, although marginally, for 10% and 20% levels of furnace slag, and then there was

a subsequent decrease in the flexural strength. On the other hand for 10% fixed marble dust content, for 28 days curing, the flexural strength increased up to 10% level of furnace slag replacement, and then decreased appreciably for 20% and 30% replacement levels. A similar trend is observed for a fixed marble dust content of 15%, with a change that the strength decrease is not as significant at the 20% and 30% furnace slag replacement level as compared to the 10% level.

These observations indicate that the optimum replacement level of sand with both the materials, marble dust and furnace slag used in combination is 25 to 30% only.

The highest early age flexural strength, 7 days, could be achieved by using only 15% marble dust as sand replacement or 15% marble dust with 10% furnace slag in combination, indicating that marble dust replacement helped in early age flexural strength development.

The highest strength in flexure at 28 days could be achieved by using a combination of both the materials with 10% furnace slag and 10% marble dust. This indicates that the pozzolanic reaction of furnace slag contributes more to gain in flexural strength from a period of 7 to 28 days, with lesser amount of marble dust.

Fig 4.16 shows the percentage variation in flexural strength as compared to the control mix, for all the mixes after 7 days of curing.

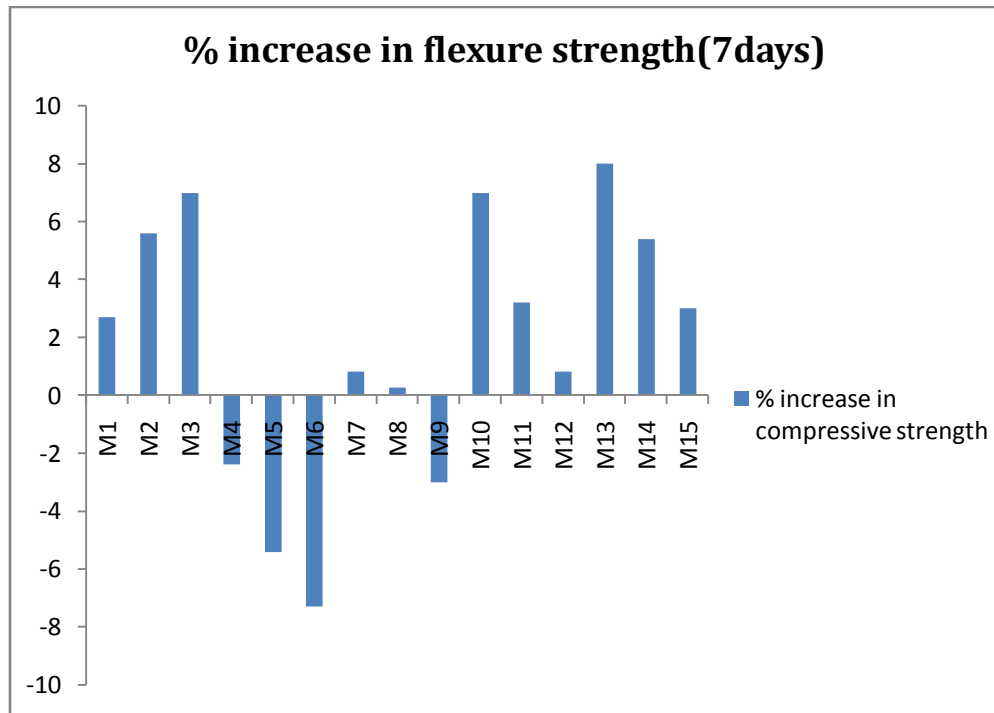


Fig 4.16 Percentage variation in flexural strength of various mixes as compared to the normal mix at 7 days

It can be observed from the figure 4.16 that all the mixes containing only furnace slag or higher percentages of furnace slag with less amount of marble dust, when used in combination could not achieve the control mix flexural strength, reinforcing the point that use of furnace slag is not suitable for early age flexural strength gain. The increase in the flexural strength for all mixes containing higher percentages of marble dust was due to the cementitious property of marble dust which gets developed by hydration of calcite and C_3A chemically, and also it act as a filler material in the mix which decrease the porosity of the concrete mix.

For the furnace slag the decrease in the strength may be due to increase in demand for the cement in the mix. This happens as the furnace slag has a large surface area than the sand. As the surface area increases, the demand for cement also increases, though this remains the same for all the concrete mixes, thus leading to a decreased flexural strength.

Fig 4.17 shows the percentage variation in compressive strength as compared to the control mix, for all the mixes after 28 days curing.

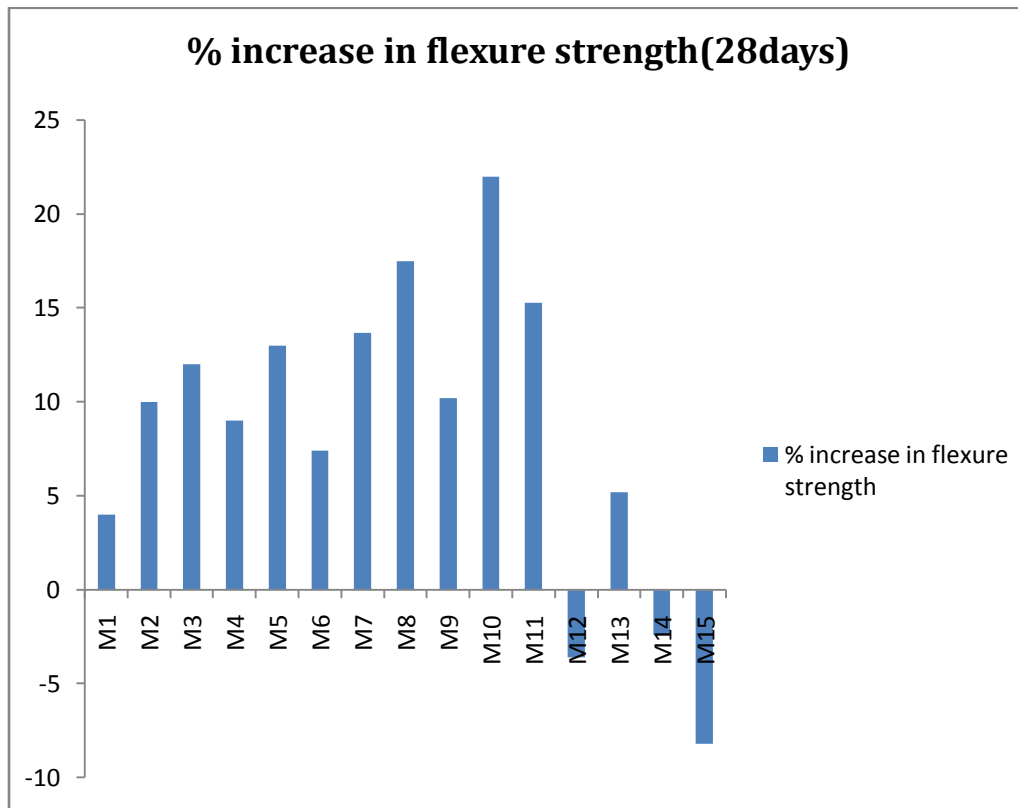


Fig 4.17Percentage variation in flexural strength of various mixes as compared to the normal mix at 28 days

It can be observed from the figure 4.17 that all the mixes having a combined replacement content more than 35% could not achieve the flexural strength of control mix itself, in fact the percentage decrease was observed to be in the range of 4 to 8%. For most of the other mixes, individually or in combination an increase of 10% and a maximum increase of 22% was observed. This increase in flexural strength is due to the hydraulic reaction of the slag with available calcium hydroxide (CH) and alkalis to form an additional C-S-H.

5.1 GENERAL

An experimental program was devised to study the strength characteristics of pavement quality concrete containing marble dust and furnace slag as partial replacement of fine aggregates or sand. Tests were performed on hard concrete cured under standard laboratory conditions, and compressive and flexural strengths were observed at curing ages of 7, 28, 56 days. A discussion of results was carried out and the major conclusions drawn from the study are elaborated here in.

5.2 COMPRESSIVE STRENGTH OF PAVEMENT QUALITY CONCRETE

- Furnace slag, being a pozzolanic material, results in less early age compressive strength, but there is a gain in later age strengths due to the pozzolanic reaction which sets in late.
- Furnace slag can be used as an ideal replacement for sand if later ages strengths are a priority, whereas marble dust would serve well for mixes where early age strength is the need.
- At early ages, even though marble dust is used in higher quantity, the furnace slag variation dictates the effect on the compressive strength of concrete at early ages.
- To achieve higher than designated compressive strength, the optimum replacement level of sand with both the materials, marble dust and furnace slag used in combination is 20 to 25% only.
- Highest early age strength, 7 days, could be achieved by using only 10% marble dust as sand replacement indicating that marble dust replacement helps in early age strength development.
- Highest strength in compression at 28 days could be achieved by using a combination of the two materials either 10% furnace slag or 15% marble dust or 20% furnace slag and 5% marble dust. This indicates that the pozzolanic reaction of furnace slag helps in gaining strength from a period of 7 to 28 days.

- Highest strength at 56 days for a combination of 20% furnace slag and 5% marble dust further corroborates the point made earlier.
- As the compressive strength increase is significant for mixes containing marble dust and furnace slag, these materials can be used in combination up to certain limits of 20 to 25% in development of pavement quality concrete, that will not only fulfil the conditions but also save the other ingredients in the concrete and leads to economic design for the concrete slab of the pavement.

5.3 FLEXURAL STRENGTH OF PAVEMENT QUALITY CONCRETE

- Furnace slag, being a pozzolanic material, results in less early age flexural strength, similar to compressive strength, but there is a gain in later age strengths
- Furnace slag can be used as an ideal replacement for sand if later ages flexural strengths are a priority, whereas marble dust would serve well for mixes where early age flexural strength is the need.
- At early ages, even though marble dust is used in higher quantity, the furnace slag variation dictates the effect on the flexural strength, on similar line as compressive strength, of concrete at early ages.
- To achieve higher than designated compressive strength, the optimum replacement level of sand with both the materials, marble dust and furnace slag used in combination is 25 to 30% only.
- Highest early age flexural strength, 7 days, could be achieved by using only 15% marble dust as sand replacement or 15% marble dust with 10% furnace slag in combination, indicating that marble dust replacement helps in early age strength development.
- Highest strength in flexure at 28 days could be achieved by using a combination of both the materials with 10% furnace slag and 10% marble dust. This indicates that the pozzolanic reaction of furnace slag contributes more to gain in flexural strength from a period of 7 to 28 days, with lesser amount of marble dust.
- As the flexural strength increase is significant for mixes containing marble dust and furnace slag, these materials can be used in combination up to certain limits of 25 to 30% in development of pavement quality concrete, that will not only fulfil the

conditions but also save the other ingredients in the concrete and leads to economic design for the concrete slab of the pavement.

5.4 SCOPE FOR FURTHER WORK

- In the present study experimental program was devised to study the strength characteristics of mixes containing marble dust and furnace slag. The work can be extended to study the durability characteristics as well.
- The performance of the pavement quality concrete slabs containing marble dust and furnace slag can be evaluated by constructing the trial stretches. The behaviour of these PQC slabs can be analysed under repetitive loading for the fatigue life consumed.

REFERENCES

1. Aliabdo, A. A., AbdElmoaty, A. E. M., &Auda, E. M. (2014). Re-use of waste marble dust in the production of cement and concrete. *Construction and Building Materials*, 50, 28-41.
2. Alsadey, S. (2012). Influence of superplasticizer on strength of concrete. *Int J Res EngTechnol*, 1(3).
3. Bahar, D. (2010). The effect of the using waste marble dust as fine sand on the mechanical properties of the concrete. *International journal of physical sciences*, 5(9), 1372-1380.
4. Barišić, I., Dimter, S., &Netinger, I. (2010). Possibilities of application of slag in road construction. *Technical Gazette* 17(4), 523-528.
5. Berndt, M. L. (2009). Properties of sustainable concrete containing fly ash, slag and recycled concrete aggregate. *Construction and Building Materials*, 23(7), 2606-2613.
6. Boukendakdji, O., Kadri, E. H., & Kenai, S. (2012). Effects of granulated blast furnace slag and superplasticizer type on the fresh properties and compressive strength of self-compacting concrete. *Cement and Concrete Composites*, 34(4), 583-590.
7. Buddhdev, B. G., &Varia, H. R. (2014) Feasibility Study on Application of Blast Furnace Slag in Pavement Concrete. *International Journal of Innovative Research in Science, Engineering and Technology* Vol. 3, Issue 3.
8. Ergün, A. (2011). Effects of the usage of diatomite and waste marble powder as partial replacement of cement on the mechanical properties of concrete. *Construction and building materials*, 25(2), 806-812.
9. Etxeberria, M., Pacheco, C., Meneses, J. M., &Berridi, I. (2010). Properties of concrete using metallurgical industrial by-products as aggregates. *Construction and Building Materials*, 24(9), 1594-1600.
10. Hebhouh, H., Aoun, H., Belachia, M., Houari, H., &Ghorbel, E. (2011). Use of waste marble aggregates in concrete. *Construction and Building Materials*, 25(3), 1167-1171.
11. IS: 456-2000: Code of practice- plain and reinforced concrete, Bureau of Indian Standard, New Delhi-2000.
12. IS: 516-1959 (Reaffirmed 2004): Methods of tests for strength of concrete, Bureau of Indian Standard, New Delhi-2004.

13. IRC: 58-2002, "Guideline for Design of Rigid Pavements for Highways." The Indian Road Congress, New Delhi, 2002.
14. IRC 44: 2008, "Guidelines for cement concrete mix design for pavement", The Indian Road Congress, New Delhi, 2008.
15. IS: 10262-1982 (Reaffirmed 2004): Recommended guidelines for concrete mix design, Bureau of Indian Standard, New Delhi-2004
16. IS: 8112-1989 (Reaffirmed 2005): Specification for 43 Grade Ordinary Portland cement, Bureau of Indian Standard, New Delhi-2005.
17. IS: 9103-1999 (Reaffirmed 2004): Concrete Admixtures-Specifications, Bureau of Indian Standard, New Delhi-2004.
18. IS: 383-1970: Specification for Coarse and Fine Aggregates from Natural Sources for Concrete, Bureau of Indian Standard, New Delhi-1970.
19. IS: 1199-1959 (Reaffirmed 1999): Methods of Sampling and Analysis of Concrete, Bureau of Indian Standard, New Delhi-1999.
20. IS: 2386 (Part I, III)-1963: Methods of Test for Aggregates for Concrete, Bureau of Indian Standard, New Delhi-1963.
21. IS: 4031 (Part 4, 5&6)-1988: Methods of Physical Tests for Hydraulic Cement, Bureau of Indian Standard, New Delhi-1988.
22. Kumar, S., Kumar, R., Bandopadhyay, A., Alex, T. C., Ravi Kumar, B., Das, S. K., & Mehrotra, S. P. (2008). Mechanical activation of granulated blast furnace slag and its effect on the properties and structure of portland slag cement. *Cement and Concrete Composites*, 30(8), 679-685.
23. Pathan, V. G., & Pathan, M. G. (2014) Feasibility and Need of use of Waste Marble Powder in Concrete Production. *IOSR Journal of Mechanical and Civil Engineering* pp 23-26.
24. Rai, B., Khan Naushad, H., TabinRushad, S., & Duggal, S. K. (2011). Influence of Marble powder/granules in Concrete mix. *International journal of civil and structural engineering*, 1(4), 827-834.
25. Roy D.K.S. 2011 "Performance of Blast Furnace Slag Concrete with Partial Replacement of Sand by Fly Ash " *International Journal of Earth Sciences and Engineering* Volume 04, pp949-952.

26. Tamrakar, R., & Mishra, M. S. (2013). "Experimental Studies on Property of Concrete due to Different Ingredient based Super Plasticizer". International Journal of Science, Engineering and Technology Research, volume 2, no 5, pp-1036.
27. Teng, S., Lim, T. Y. D., & Sabet Divsholi, B. (2013). Durability and mechanical properties of high strength concrete incorporating ultra fine Ground Granulated Blast-furnace Slag. Construction and Building Materials, 40, 875-881.
28. Topcu, B. I., Bilir, T., Uygunog, T. (2009) Effect of waste marble dust content as filler on properties of self-compacting concrete Construction and Building Materials Vol. 23 page no. 1947-1953.
29. Yusof M.A.W, 2005 "Investigating the Potential for Incorporating Tin Slag in Road Pavements" A Thesis submitted to the University of Nottingham for the degree of Doctor of Philosophy pp 41-65.

DESIGN OF PAVEMENT QUALITY CONCRETE SLAB AS PER IRC GUIDELINES

This annexure deals with the design of the Pavement Quality Concrete slab for the various mixes in reference to the guidelines of the IRC: 58-2002.

PROCEDURE FOR DESIGN OF SLAB THICKNESS AS PER IRC 58-2002

Step1. Stipulate design values for the various parameters.

Step2. Select a trial design thickness of pavement slab.

Step3. From the given data, cumulative repetition in 20 yrs. can be calculated from the formula which is given below:

$$C = A \times 365 \left[\frac{(1+r)^n - 1}{r} \right]$$

Where, C = Cumulative number of axles during the design period.

A = Initial number of axles per day in the year when the road is operational.

r = Annual rate of growth of commercial traffic (expressed in decimals).

n = Design period in years.

Design traffic can be calculated by 25% of cumulative repetition.

Step 4. The Single and Tandem Axle load is multiplied with a factor of 1.2 respectively.

Step 5. Stress (kg/cm²) is calculated from the given graphs as mentioned in IRC 58: 2002 (Graph between slab thickness and flexure strength).

Step 6. The stress ratio is calculated as $\frac{\text{Stress}}{\text{Flexure strength}}$

Step7. Expected Repetition is calculated from the Design Traffic which is multiplied with a percentage of respective Axle loads.

Step8. Allowable Repetition is calculated from the Table 6 of IRC: 58.

Step 9. Fatigue life consumed is calculated which is the ratio of fatigue life (N) and expected repetition (n). The design is unsafe if the cumulative fatigue life consumed is less than 1.0. If unsafe then select a higher thickness and repeat the steps.

Step10. Compute the temperature stress at the edge and if the sum of the temperature stress and the flexural stress due to the highest wheel load is greater than the modulus of rupture, select a higher thickness. Section 5.2 considers an example for the calculation of the thickness of the slab for the mix M10 (10% Furnace Slag and 10% Marble Dust).

DESIGN OF RIGID PAVEMENT FOR MIX M10 AS PER IRC: 58-2002:

The design parameters for the design of slab are:

Design life	30 year
Design wheel load	7000 kg
Present traffic intensity	474 CVD
28 days Compressive strength of concrete	605 kg/cm ²
Flexural strength of cement concrete	60.5 kg/cm²
Sub grade CBR	7.00 %
Thickness of Dry Lean Concrete	15 cm
Tyre pressure	8 kg/cm ²
Elastic modulus of concrete	3×10 ⁵ kg/cm ²
Poisson's ratio	0.15
Coefficient of thermal coefficient of concrete	10×10 ⁻⁶ /°C
Spacing of contraction joints	4.5 m
Width of slab	3.5 m
Concrete slab thickness	20.1 cm

The total repetitions of the single axle and tandem axle loads are as follows:

Single Axle Loads		Tendon Axle Loads	
Load in tonnes	Expected repetition	Loads on tonnes	Expected repetitions
27-29	0.00		
25-27	0.00		
23-25	0.00	42-46	0.00
21-23	0.00	38-42	0.00
19-21	0.00	34-38	0.00
17-19	0.00	30-34	0.00
15-17	2.08	26-30	0.00
13-15	6.25	22-26	1.74
11-13	18.06	18-22	7.99
09-11	17.71	14-18	12.50
< 09	26.04	< 14	7.64
Total	70.14	Total	29.86

- Cumulative repetitions in 30 years 45978340
- Design traffic 11494585
- Radius of relative Stiffness (I) 52.328 cm

Fatigue analysis for the PQC slab

Axle load	AL*LSF	Stress from charts	Stress ratio	Expected repetition	Fatigue life, N	Fatigue life consumed
1	2	3	4	5	6	5/6
Single Axle						
20	24	37.58	0.62	0	17139.48	0.00
18	21.6	34.62	0.57	0	66724.3	0.00
16	19.2	31.56	0.52	239471	306464.7	0.7813
14	16.8	28.4	0.47	718412	5428823	0.1323
12	14.4	25.14	0.42	2075411	Infinity	0.00
Tandem Axle						
36	43.2	30.56	0.51	0	599875	0.00
32	38.4	24.74	0.41	0	Infinity	0.00
Cumulative fatigue damage/ Life consumed						0.9137
Check for fatigue life						Safe

Therefore, the assumed slab thickness of 20.1 cm is safe for the defined traffic and concrete mix characteristics.

Similarly for all the mixes the slab thickness is calculated and concrete slab is design for the various mixes and the required thicknesses are compared for the target control and control mix.

SAVING OF MATERIAL IN DESIGN OF SLAB THICKNESS PAVEMENT

According to the result of the study if the flexural strength increases there is a decrease in slab thickness which directly decreases the volume of concrete and thus saves in the materials. For the mix M10 (10%MD &10%FS) there is a decrease of 30mm in the thickness of slab. Similarly for the other mixes the variation in thickness is shown in the table 5.1

Saving in concrete pavement thickness (mm)

Mix ID	Saving in concrete pavement thickness	Mix ID	Saving in concrete pavement thickness
Control mix	-	M8 (MD 5% & FS20%)	27 mm
M1 (MD 5% & FS 0%)	7 mm	M9 (MD 5% & FS 30%)	16 mm
M2 (MD 10% & FS 0%)	16 mm	M10 (MD10% & FS 10%)	31 mm
M3 (MD 15% & FS 0%)	18 mm	M11 (MD10% & FS20%)	23 mm
M4 (MD 0% & FS 10%)	14 mm	M12 (MD10% & FS 30%)	-6 mm
M5 (MD 0% & FS 20%)	19 mm	M13 (MD15% & FS 10%)	9 mm
M6 (MD 0% & FS 30%)	12 mm	M14 (MD15% & FS 20%)	-2 mm
M7 (MD 5% & FS10 %)	21 mm	M15 (MD15% & FS 30%)	-14 mm

CONCLUSION

Saving in the concrete slab thickness indicates that the volume required also decrease. Therefore there is a saving in the materials for the concrete which gives an economical support to the pavement. As the Marble dust is a waste product and its utilization not only gives satisfactory results but also increase the concrete strength which leads to economy. On the other hand furnace slag is also a waste product, have no cost at all and it can also use in the concrete for the better result and economic reason. The total saving in concrete ingredients with the use of marble dust and furnace slag is shown in the table below.

Mix	Slab Pavement Thickness(mm)	Saving in PQC slab thickness (mm)	Saving in m ³ of concrete for 1 km two lane highway	Saving in cement content (kg)	Saving in fine aggregate (kg)	Saving in coarse aggregate (20mm) kg	Saving in coarse aggregate (10mm) kg
Control mix	232	-	-	-	-	-	-
M1 (MD 5% & FS 0%)	225	7	59.5	22907.5	35313.3	43554	29452.5
M2 (MD 10% & FS 0%)	216	16	136	52360	80716	99552	67320
M3 (MD 15% & FS 0%)	214	18	153	58905	90805.5	111996	75735
M4 (MD 0% & FS 10%)	218	14	119	45815	70626.5	87108	58905
M5 (MD 0% & FS 20%)	213	19	161	61985	95553.5	117852	79695
M6 (MD 0% & FS 30%)	22	12	102	39270	60537	74664	50490
M7 (MD 5% & FS10 %)	211	21	178	68530	105643	130296	88110
M8 (MD 5% & FS20%)	205	27	230	88550	136505	168360	113850
M9 (MD 5% & FS 30%)	216	16	136	52360	80716	99552	67320
M10 (MD10% & FS 10%)	210	31	263	101255	156091	192516	130185
M11 (MD10% & FS20%)	209	23	195	75075	115733	142740	96525
M12 (MD10% & FS 30%)	238	-6	-51	-19635	-30269	-37332	-25245
M13 (MD15% & FS 10%)	223	9	76	29260	45106	55632	37620
M14 (MD15% & FS 20%)	234	-2	-17	-6545	-10090	-12444	-8415
M15 (MD15% & FS 30%)	246	-14	-119	-45815	-70627	-87108	-58905

Saving in materials in concrete with the use of marble dust and furnace slag

