



# Mitigation For Fire-Induced Spalling in Concrete by Reused Tyre Polymer Fibres

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## Abstract:

*With the increased incidents of major fires in buildings; assessment, repairs and rehabilitation of fire damaged structures has become a topical interest. This is a specialized field involves expertise in many areas like concrete technology, material science and testing, structural engineering, repair materials and techniques etc. Research and developmental efforts are being carried out in this area and other related disciplines. In this topic the experience of real life problems are presented which add immense value to this. This topic also gives a Comprehensive knowledge on the overall strategy for the restoration of fire damaged buildings and also presents a critical appraisal of the assessment procedures by different non destructive techniques, specifications and execution of repair techniques. The experimentation has been done to find out the impact of the fire on concrete and reinforcement steel bars by heating. The heated samples are rapidly cooled by quenching in water and normally by air cooling. The change in the mechanical properties are studied using universal testing machine (UTM), CTM, two point flexural test and the microscopic study of grain size and grain structure is studied by scanning electron microscope (SEM). This study is conducted to accomplish some predefined objectives. These objectives are to:*

*A. Develop a better understanding of fire-induced spalling and spalling-mitigation mechanisms;*

*B. Investigate the effect of tyres fibres for preventing fire-induced spalling of plain concrete and it includes*

*1. Density of R.C.C structure*

*2. visual information of fire effect on R.C.C structure*

*3. Compressive strength of R.C.C structure*

*4. Tensile strength of structure.*

*C. Develop predictive numerical models for fire-induced spalling of concrete and to carryout brief study on polymers.*

## Keywords

*Mitigation, Fire-induced spalling, Tyre polymer fibres*

## 1. Introduction

Concrete is a composite material widely used in construction sector. When used in buildings and industries it is likely to be subjected to fires of different intensities. Structural members in buildings have to satisfy certain fire safety requirements specified in building codes. Behaviour of concrete in fire has been studied by many researchers and it has been observed that properties of concrete Such as compressive strength, tensile strength, modulus of elasticity, etc. are adversely affected at elevated temperature when exposed to fire. The change of mechanical properties also depend on several factors e.g. rate of heating, type of aggregate used, size of specimen, moisture content, age of specimen, etc. Approximately 65% to 75% of concrete volume is occupied by aggregates. The commonly used aggregate are stable up to a temperature range of 3000C–3500C but when the temperature rises to 5000C–6000C the physical and chemical changes in the aggregate occur which result in increase in volume of aggregates. The most of non-siliceous aggregates are stable up to temperature of 6000C whereas at higher temperature the calcareous materials such as calcite, magnetite and dolomite dissociate into an oxide and carbon dioxide. The degradation in the properties of concrete at elevated temperature is mainly due to mechanical and chemical changes in the aggregate and cements paste. The effect of elevated temperature on the concrete is observed by loss in mechanical properties and degradation of concrete. It is mainly due to formation of cracks and micro cracks on the surface of the concrete The explosive spalling on the surface of high strength concrete at temperature range of 2000C–3250C due to internal pore pressure and thermal stresses The type of aggregates used in concrete has a significant effect on properties of concrete at elevated temperature concrete mixes produced by using crushed lime stone aggregates showed lower reduction in compressive strength at elevated temperature as compared to that of river gravel concrete mixes, because lime stone aggregate have low thermal expansion than siliceous aggregates. The decomposition of siliceous aggregate



takes place at 57 °C and causes volume expansion whereas the lime stone aggregate decompose at 800°C–900°C and expands with increase in temperature. Kizilkanat et al. (2013) reported that thermal conductivity of concrete containing calcareous aggregates was lower than that of concrete containing siliceous aggregates at elevated temperature.

- We are all aware of the damage that fire can cause in terms of loss of life, homes and livelihoods.
- A study of 16 industrialized nations (13 in Europe plus the USA, Canada and Japan) found that, in a typical year, the number of people killed by fires was 1 to 2 per 100,000 inhabitants and the total cost of fire damage amounted to 0.2% to 0.3% of GNP.
- The extent of such damage depends on a number of factors such as building design and use, structural performance, fire extinguishing devices and evacuation procedures.
- Appropriate design and choice of materials is crucial in ensuring fire safe construction, Codes and regulations on fire safety are updated continually, usually as a result of research and development.

#### NEED TO REUSE OF WASTE TYRES IN INDIA

- Globally the tire production is estimated to be 1 billion per year, With the exponential growth in number of automobiles in India during recent years, the demand of tires as original equipment and as replacement has also increased.
- In India an annual cumulative growth rate of 8% is expected in buses, trucks, cars/jeep/taxis, Considering the average life of the tyres used in these vehicles as 10 years after rethreading twice, the total number of waste disposable tyres will be in the order of 112 million per year.
- Approximately, one tire is discarded per person per year.
- These tires are among the largest and most problematic type of waste, due to the large volume produced and their durability.
- Accumulations of discarded waste tires have been a major concern because the waste rubber is not easily biodegradable even after a long-period landfill treatment.

#### TIRE MATERIAL

- The materials of modern pneumatic tires are synthetic rubber, natural rubber, fabric and wire, along with carbon black and other chemical compounds.
- Fiber is a thread or filament from which a vegetable tissue, mineral substance, or textile is formed or dietary material containing substances such as cellulose, lignin, and pectin, that are resistant to the action of digestive enzymes.

- Natural rubber, also called India rubber or caoutchouc, as initially produced, consists of polymers of the organic compound isoprene, with minor impurities of other organic compounds, plus water.

- Forms of polyisoprene that are used as natural rubbers are classified as elastomers.

- A synthetic rubber is any artificial elastomer, These are mainly polymers synthesized from petroleum byproducts.

- Global revenues generated with synthetic rubbers are likely to rise to approximately US\$56 billion in 2020. Synthetic rubber, like natural rubber, has uses in the automotive industry for tires.

- Natural rubber, coming from latex of *Hevea brasiliensis*, is mainly poly-cis-isoprene containing traces of impurities like protein, dirt etc.

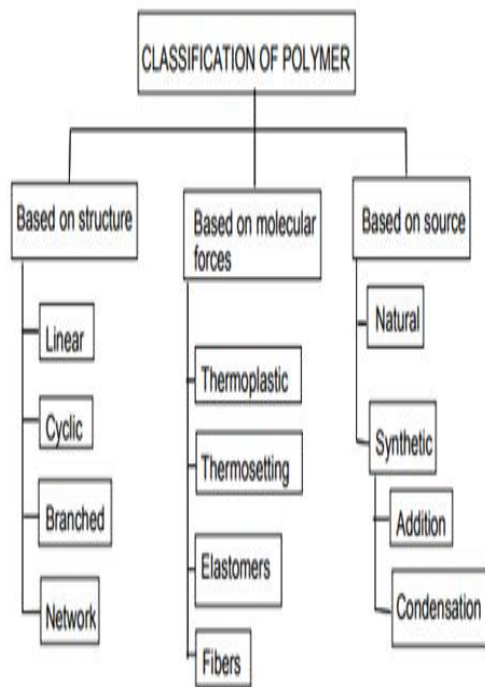
- Although it exhibits many excellent properties in terms of mechanical performance, natural rubber is often inferior to certain synthetic rubbers, especially with respect to its thermal stability and its compatibility with petroleum products.

- Synthetic rubber, like other polymers, is made from various petroleum-based monomers.

- Carbon black is a material produce by the incomplete combustion of heavy petroleum products such as FCC tar, coal tar, ethylene cracking tar, and a small amount from vegetable oil.

#### POLYMERS

- A polymer is a macromolecule, made up of many smaller repeating units called monomer. Polymers have high molecular weight in the range of several thousand or even higher. The first synthetic organic polymer polyvinylchloride was synthesized in 1838 by accidentally. Later, polystyrene was discovered in 1839.



**USE OF WASTE TYRES**

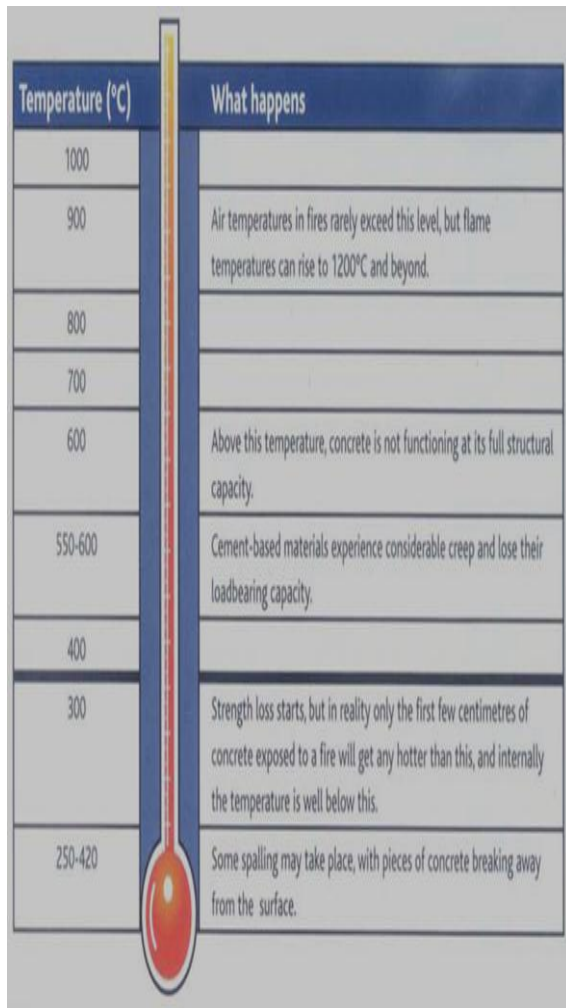
- Recycled waste-tire rubbers have been used in different application.
- It has been used as a fuel for cement kiln, as feedstock for making carbon black, and as artificial reefs in marine environment.
- It has also been used as a playground matt, erosion control, highway crash barriers, guard rail posts, noise barriers, and in asphalt pavement mixtures.
- Other construction products are also based on rubber powder obtained from the cryogenic milling of tires mixed with asphalt or bituminous materials.
- Over the past two decades, research had been performed to study the availability of using waste tire rubber in concrete mixes.
- So, prevent the environmental problem from growing, recycling tire is an innovative idea or way in this case.
- 1854 First recorded observation of fire spalling of concrete. Probably the first description of the spalling behavior of concrete during fire was made in a publication by Barret . He described a discussion where Mr. Tite stated that “if “FLINT” was used aggregate in concrete it would “split, and yield under the action of fire”.

**UNPROTECTED CONSTRUCTION MATERIALS PERFORMANCE IN FIRE**

- Polypropylene fibers (PPF) are used in concrete principally to reduce plastic shrinkage cracking, but also to prevent explosive spalling of concrete exposed to fire.
- Concrete is normally considered inherently fire resistant, due to its low thermal conductivity and non-combustibility. However, it does suffer from fire-induced spalling, which is one of the most complex and hence poorly understood phenomena in fire engineering.
- Fire-induced spalling can be explosive and it can occur at temperatures as low as 200 °C. It can significantly reduce the fire resistance of concrete structures, due to
  - Reduction in cross- section area of structural elements;
  - (2) loss of thermal protection to the internal steel reinforcement
- In recently years, there have been many developments in concrete technology and modern construction now uses high-performance, high-strength and self-compacting concretes.

**WHAT HAPPENS TO CONCRETE IN A FIRE**

- Fires are caused by accident, energy sources or natural means, but the majority of fires in buildings are caused by human error.
- Once a fire starts and the contents and/or materials in a building are burning, then the fire spreads via radiation, convection or conduction with flames reaching temperatures of between 600°C and 1200°C.
- Harm is caused by a combination of the effects of smoke and gases, which are emitted from burning materials, and the effects of flames and high air temperatures.
- Concrete does not burn – it cannot be ‘set on fire’ like other materials in a building and it does not emit any toxic fumes when affected by fire.
- It will also not produce smoke or drip molten particles, unlike some plastics and metals, so it does not add to the fire load.
- For these reasons concrete is said to have a high degree of fire resistance and, in the majority of applications, concrete can be described as virtually ‘fireproof’.



#### CONCRETE IN FIRE: PHYSICAL PROCESSES

- This excellent performance is due in the main to concrete's constituent materials (i.e. cement and aggregates) which, when chemically combined within concrete, form a material that is essentially inert and, importantly for fire safety design, has a relatively poor thermal conductivity.

- It is this slow rate of heat transfer (conductivity) that enables concrete to act as an effective fire shield not only between adjacent spaces, but also to protect itself from fire damage.

- The rate of increase of temperature through the cross section of a concrete element is relatively slow and so internal zones do not reach the same high temperatures as a surface exposed to flames.

- A standard ISO 834/BS 476 fire test on 160 mm wide x 300 mm deep concrete beams has shown that, after one hour of exposure on three sides, while a temperature of 600°C is reached at 16 mm from the surface.

#### SPALLING OF CONCRETE

- Spalling is part of concrete's normal response to the high temperatures experienced in a fire. One of the most complex and hence poorly understood behavioral characteristics in the reaction of concrete to high temperature or fire is the phenomenon of "explosive spalling".

- Spalling may significantly reduce or even eliminate the layer of concrete cover over the reinforcement bars, thereby exposing the reinforcement to high temperature, leading to a reduction of strength of the steel and hence a deterioration of mechanical properties of the structure as a whole.

- Another significant effect of spalling upon the physical strength of structures occur via reduction of the cross-section of concrete available to support the imposed loading, increasing the stress on the remaining areas of concrete available to support the imposed loading, increasing the stress on the remaining area of concrete.

- This process is often assumed to occur only at high temperatures, yet it has also been observed in the early stages of fire and at a temperature as low as 200°C.

- Severe spalling can have deleterious effect on strength of reinforced concrete structures, due to enhanced heating of steel reinforcement.

- The mechanism leading to spalling is generally thought to involve high thermal stresses resulting from rapid heating and/or large buildups of pressure due to moisture evaporation within the porous concrete, which the structure of concrete is not able to dissipate.

- The first systematic attempt to categorize different kinds of fire spalling of concrete was made by Gary(1917) in his review of work conducted between 1910-1916.

- He found from fire tests on specially built houses, that fire spalling could occur in the following forms:

- Aggregate Spalling – crater formed spalling attributed to the mineralogical character of the aggregates.

- dampness Surface Spalling – disc shaped violent flaking, especially in pressure stressed walls, probably caused by water.

- Corner Spalling – violent spalling of corners, probably caused by water damp as well as due to temperature stresses due to bilateral fast heating up.

- Explosive Spalling – very violent spalling of large, up to 1m<sup>2</sup>, pieces from walls. Some pieces are thrown 12 m, by the force.



## 2. Literature Review

### 1) “Assessment of concrete susceptibility to fire spalling” Isabella Hager (2015)

The assessment of concrete behavior at high temperature is done by a variety of tests carried out on specimens of different sizes. Small-scale tests examine concrete's behavior when exposed to elevated temperature, while full-scale fire tests are carried out on full-sized concrete elements in which the boundary conditions, external load and conditioning correspond to design assumptions. Complementary to these is the medium-scale test carried out on a portion of a slab's surface area which has been exposed to fire, ca. 1m<sup>2</sup>. Such medium-scale tests are often used as a cost-effective solution to verify the behavior of a specific concrete mix in fire conditions. This paper reviews the existing furnaces, testing procedures and laboratory setups used to assess a material's tendency to spall. Its objective is to emphasize the need to unify spalling risk assessment procedures by establishing recommended guidelines for testing. Full scale tests are the most representative, directly showing the qualitative and quantitative behavior of structural concrete elements subjected to fire. The disadvantage is that tests performed using large furnaces are both costly and are unsuitable for testing a large number of different concrete mixes. To overcome this limitation, and thanks to the dimensions of a large furnace, many small-sized slabs can be tested at the same time, thereby making it possible to examine different concrete mixes, or various specimen sizes during a single test. Spalling events are observed through a small hole and recorded using a digital camera. In such tests, acoustic events are recorded using a microphone located near the specimen. In order to secure a stress state provided by flat jacks, a reference test without thermal load is made using strain gauges placed on the specimen's surface.

### 2) “Fire spalling in concrete” R. Jansson and L. Boston (2013)

A compressive strength reduction effect of almost 40% has been shown for small mortar specimens with a moisture content of 8% boiled in water for 3, 10 or 20 minutes compared with dried specimens. This shows that the presence of moisture can be a plausible factor that reduces the strength in areas where spalling in the form of surface flaking during fire exposure occurs. Boiling for 10 minutes gave a reduction of strength of 26% for the wet mortar specimens without the addition of PP fibers compared to dried specimens. The results are not unique as it has been seen in many test series in the past that the strength is reduced when moisture is trapped inside heated concrete, i.e. if the test is

performed when the temperature equilibrium is reached but not the moisture equilibrium. By testing small specimens and different boiling times the influence of pore pressure does not seem to be the main reason for this reduction in strength as no influence of the time of boiling was seen.

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- 1866 Recognition that rapid cooling of heated concrete building elements could precipitate spalling. According to INGLE, some of the numerous instances of destruction by fire of concrete buildings, which were supposed to be fire resistant, are probably due to the application of water during fire fighting. This is probably a rare scenario but there is at least one documented example of this.

- During a fire event, described by the Swedish Tariff Association, pre-stressed beams were used as targets for distributing water in the fire enclosure with the consequence that a large part of the webs of the beams spelled away.

- In contrast with this experience it was surmised by KORDINA during a workshop in BRAUNSCHWEIG on the subject of fire resistance of pre-stressed concrete that the hose steam test did not appear to result in dangerous spalling.

### 3) “Effect of High Temperature on Compressive Strength of Concrete” Ashok R (2015)

This work was carried out to assess the effect of high temperatures on compressive strength of concrete. Effect of fire on concrete is a relatively less explored area because of the lesser use of RCC structures in Europe/USA as compared to steel structures. Ninety concrete cubes of 150 mm size, divided equally over three different grades of design mix concrete viz. M: 30, M: 25 & M: 20 were cast. After 28 days' curing & 24 hours' air drying, the cubes were subjected to different temperatures in the range of 200°C to 800°C, for two different exposure times viz. 1 hour & 2 hours in an electric furnace. The heated cubes were cooled at room temperature for 24 hours & then subjected to cube compressive strength test. Results revealed fairly robust performance up to 500°C, with strength coming down only slightly. Up to this stage, the fire affected structural members remain serviceable although the factor of safety would come down. Affected structure/ structural members would require minor repairs & patchwork to recuperate. At or @ 650°C, the fall in concrete strength would be a cause for



concern. Major retrofitting might be required. At or beyond 650°C, concrete stood completely decimated.

#### 4) “Performance of Polypropylene Fiber Reinforced Concrete” Milind V. Mohod (2015)

The paper deals with the effects of addition of various proportions of polypropylene fibres on the properties of High strength concrete (M30 and M40 mixes). An experimental program was carried out to explore its effects on compressive, tensile, flexural strength under different curing condition. The main aim of the investigation program is to study the effect of Polypropylene fiber mix by varying content such as 0%, 0.5%, 1%, 1.5% & 2% and finding the optimum Polypropylene fiber content. The concrete specimens were tested at different age level for mechanical properties of concrete, namely, cube compressive strength, split tensile strength, flexural strength. A detailed study was carried out for curing conditions. Half of the concrete specimens were left exposed to the surrounding to cure by themselves and the remaining half were cured in a curing tank. Initially the concrete specimen's shows appreciable strength for irregular curing but as the days advances the curing specimens gave satisfactory strength. A notable increase in the compressive, tensile and flexural strength was observed. However, further investigations were highly recommended and should be carried out to understand more mechanical properties of fibre reinforced concrete.

### 3. Methodology

It is the method followed to perform the experiment. In this section we have made step wise procedure to perform experiment which is briefly described as follows:

- 1) Mix design
- 2) Batching
- 3) Experimental programmed of casting
- 4) Mixing
- 5) Compaction
- 6) Curing
- 7) Testing

#### Mix design

Mix design is the process of selection of suitable ingredients of concrete and to determine their properties with object of producing concrete of certain maximum strength and durability, as economical as possible. The purpose of designing is to achieve the stipulated minimum strength, durability and to make the concrete in the most economical manner.

#### Batching

The measurement of materials for making concrete is known as batching. There are two methods of batching:

- 1) Volume batching

- 2) Weigh batching

Strictly speaking, weigh batching is the correct method of measuring the materials. Use of weight system in batching, facilitates accuracy, flexibility and simplicity.

#### Experimental Program

A schedule is framed to study the interaction of paper mill sludge with concrete. Under this schedule performance of three experimental tests is carried

- 1) Compression strength test
- 2) Split tensile strength test
- 3) Flexure strength test
- 4) Thermo gravimetric Analysis (TGA).
- 5) Differential Thermal Analysis (DTA)
- 6) X-Ray Diffraction (XRD)

Mix design (as per IS10262:2009 & IS456:2000)

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determine their properties with object of producing concrete of certain maximum strength and durability, as economical as possible. The purpose of designing is to achieve the stipulated minimum strength, durability and to make the concrete in the most economical manner.

[1] Stipulations for proportioning

A) Grade designation : M 25

B) Type of cement : PPC grade I conforming to IS 8112

C) Maximum nominal size of aggregate : 10 mm

D) Minimum cement content : 240 kg/m<sup>3</sup>

E) Maximum water-cement ratio : 0.60

F) Workability : 50 to 75 mm (slump)

G) Exposure condition : moderate

H) Method of concrete placing: manually

J) Degree of supervision : good

K) Type of aggregate: crushed angular aggregate

M) Maximum cement content : 450 kg/m<sup>3</sup>

N) Chemical admixture type : none

[2] Test data for materials

A) Cement used: PPC conforming to IS 1489 (p I)

B) Specific gravity of cement : 3.15

C) Chemical admixture : none

D) Specific gravity of

1) coarse aggregate : 2.788

2) Fine aggregate : 2.35

E) Water absorption

i) Coarse aggregate: 0.61%

2) Fine aggregate : 0.39%

G) Sieve analysis

i) Coarse aggregate: conforming to table 2 (IS 383)

2) Fine aggregate : conforming to grading zone I of Table 4 of IS 383

Target strength for mix proportioning

$$f'_{ck} = f_{ck} + 1.65 s$$

Where,

$f'_{ck}$  = Target Average compressive strength of 28 Days



fck = Compressive strength of 28 Days

s = Standard deviation,  $s = 5 \text{ N/mm}^2$ .

Therefore, target strength =  $25 + 1.65 \times 4 = 31.6 \text{ N/mm}^2$ .

3.4.2 Selection of Water-Cement ratio

From table 5, IS 456: 2000 for RCC structure,

Maximum water-cement ratio = 0.60

Adopt water-cement ratio as 0.45,  $0.45 < 0.60$ ,

Hence o.k.

Selection of water content

(A) Tires use as coarse aggregate and cement in mix design

From table 2, as per IS10262:2009

Maximum water content = 208 liters

And for 10mm aggregate,

Estimated water content for 75-100 mm slump as per IS10262:2009

=  $208 + (208 \times 5\%)$

= 219 ltr,

Calculation of cement content

Water cement ratio = 0.45

Cement content =  $219 \div 0.45 = 486.66 \text{ Kg/m}^3$

Adopted cement content is 440 Kg/m<sup>3</sup> ( $450 < 440 > 280$ ) Kg/m<sup>3</sup>

Density of cement = 440 Kg/m<sup>3</sup>

So, provided water cement ratio =  $219/440 = 0.5$

Proportion of volume of coarse aggregate and fine aggregate content

In the present case water-cement ratio is 0.5; volume of coarse aggregate is required to be increased to decrease the fine aggregate content. Therefore, corrected proportion of volume of coarse aggregate,

Mix calculations

The mix calculations per unit volume of concrete shall be as follows:

I.) Volume of concrete =  $1 \text{ m}^3$

(A) Volume of cement =  $(\text{Mass of cement}) / (\text{specific gravity of cement}) \times 1/1000 = 0.14 \text{ m}^3$

(B) Volume of tires =  $(\text{Mass of tires}) / (\text{specific gravity of PMS}) \times 1/1000 =$

Specific gravity of tire = 1.33

C) Volume water =  $(\text{Mass of Water}) / (\text{specific gravity of water}) \times 1/1000 = 0.219 \text{ m}^3$

Volume of all aggregate (e) =  $1 - (0.139 + 0.197) = 0.667 \text{ m}^3$

Mass of course aggregate =  $0.667 \times 0.61 \times 2.788 \times 1000 = 1134.567 \text{ kg/m}^3$

Mass of fine aggregate =  $e \times \text{vol. Of fine aggregate} \times \text{sp. Gravity of fine aggregate} \times 1000$

=  $0.667 \times 0.39 \times 2.35 \times 5 \times 1000$

= 612.03 kg/m<sup>3</sup>

Final mix proportions:

1) Cement = 440 kg/m<sup>3</sup>

2) Fine aggregate = 612.03 kg/m<sup>3</sup>

3) Coarse aggregate = 1134.567 kg/m<sup>3</sup>

4) Water = 219 liters

5) water/cement ratio = 0.5

#### Final mix proportion in lab

Sr	Material	Quantity(kg/m <sup>3</sup> )	Proportion
	(1)	(2)	(3)
1	Cement	440	1
2	Sand	612.03	1.39
3	Coarse aggregate (20mm and down)	1134.567	2.59
4	Water	219	0.5 (w/c ratio)

Lab apparatus and cube casting

Materials required for each casting of M25 grade concrete:

Volume calculations:

(1) Volume of 1 cube =  $3.375 \times 10^{-3} \text{ m}^3$

(2) Volume of 1 cylinder =  $1.571 \times 10^{-3} \text{ m}^3$

(3) Volume of 1 beam =  $0.0156 \text{ m}^3$

Total volume to be filled with concrete =  $(3.375 \times 6 + 1.57 \times 3) \times 10^{-3} + 0.0156 \times 3$

= 0.068 m<sup>3</sup>

Accounting 20% for wastages =  $0.068 + (0.2 \times 0.068) = 0.08 \text{ m}^3$

#### DIFFERENT FRACTION OF TIRES NOMENCLATURE

SR NO	Specimen identification	TIRES as a coarse aggregate (%)	TIRES as a coarse aggregate KG
	(1)	(2)	(3)
1	Control mix	0	0
2	PT-30-70	30%	35
3	PT-40-60	40%	45.4
4	PT-50-50	50%	68

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