CHAPTER 3

EXPERIMENTAL PROGRAM

3.1. INTRODUCTION

This chapter describes the materials, mixing procedures, specimens' fabrications, curing, test parameters, equipments and test methods adopted in the research work. The main focus in this study is to determine the benefits of implementing waste rubber particles into concrete mixtures.

The research consists of two sections; the first section focuses on the use of rubber particles at low volume fractions up to 2.5%. Different types of rubber particles were used at low volume fractions. Also, different methods of rubber surface treatments were used to enhance the bond between rubber particles and the cement paste. Moreover, this section studies the effect of the addition of silica fume and polypropylene fibers at different rubberized concrete grades. Fractional factorial method of experimentation is used to organize the studied variable and to analyze the results.

The second section of the research focuses on the use of rubberized concrete in non-structural applications. This section includes the use of rubber particles as replacement of fine aggregate in concrete in large portions up to 100%. Also, composites of rubber-cement and rubber-epoxy are presented in this section. All rubberized concrete mixes in the second section were tested in terms of thermal and acoustic insulation.

3.2. RUBBERIZED CONCRETE AT LOW VOLUME FRACTIONS (SECTION ONE)

3.2.1. Materials Properties

3.2.1.1. Cement

Type I Ordinary Portland cement according to ASTM C 150 was used in this research for all mixes. This cement type is classified in Egyptian standard as CEM I 32.5 N. The chemical analysis and the calculated compound composition of this cement are presented in Table 3.1

3.2.1.2. Aggregate types

Natural siliceous sand was used as fine aggregates with specific gravity 2.65 and fineness modulus of 2.67. The coarse aggregate was crushed pink limestone with a nominal maximum size of 3/8 inch.

To found out the physical properties of aggregate, the following tests were conducted:

1- Specific gravity and absorption according to **ASTM C 128** requirements for fine and coarse aggregate.
2- Clay and materials finer than sieve No.200 (75μ) by washing according to **ASTM C 142/97** and **B.S. 882:1992.**
3- Sieve analysis of fine and coarse aggregate according to **ASTM C33/01**.

The sieve analysis of sand is presented in Figure 3.1 and the sieve analysis of the crushed limestone is shown in Figure 3.2. From these figures, it can be seen that the used sand and Pink limestone meets the requirement of **ASTM C33-01**. The physical propertied of the used aggregated are presented in Table 3.2.

Table 3.1 The chemical composition of cement

Chemical analysis	Percentage
Silicon dioxide **(SiO2)**	.10 %19
Iron oxide**(Fe2O3)**	3.42 %
Aluminum oxide **(Al2O3)**	5.10 %
Calcium oxide **(CaO)**	.10 %26
Magnesium oxide **(MgO)**	.03 %3
Sulfur trioxide **(SO3)**	%02.
Loss on ignition **(LOI)**	2.5 %
Calculated compound composition[*]	
Tricalcium silicate **(C$_3$S)**	%62.8
Dicalcium sislicate **(C$_2$S)**	%7.4
Tricalcium aluminate **(C$_3$A)**	15.4 %
Tetracalcium aluminoferrite **(C$_4$AF)**	%10.4

* Bogue's equations were used to calculate the approximate proportions of the four main minerals in Portland cement clinker.

Table 3.2 Properties of the used aggregates

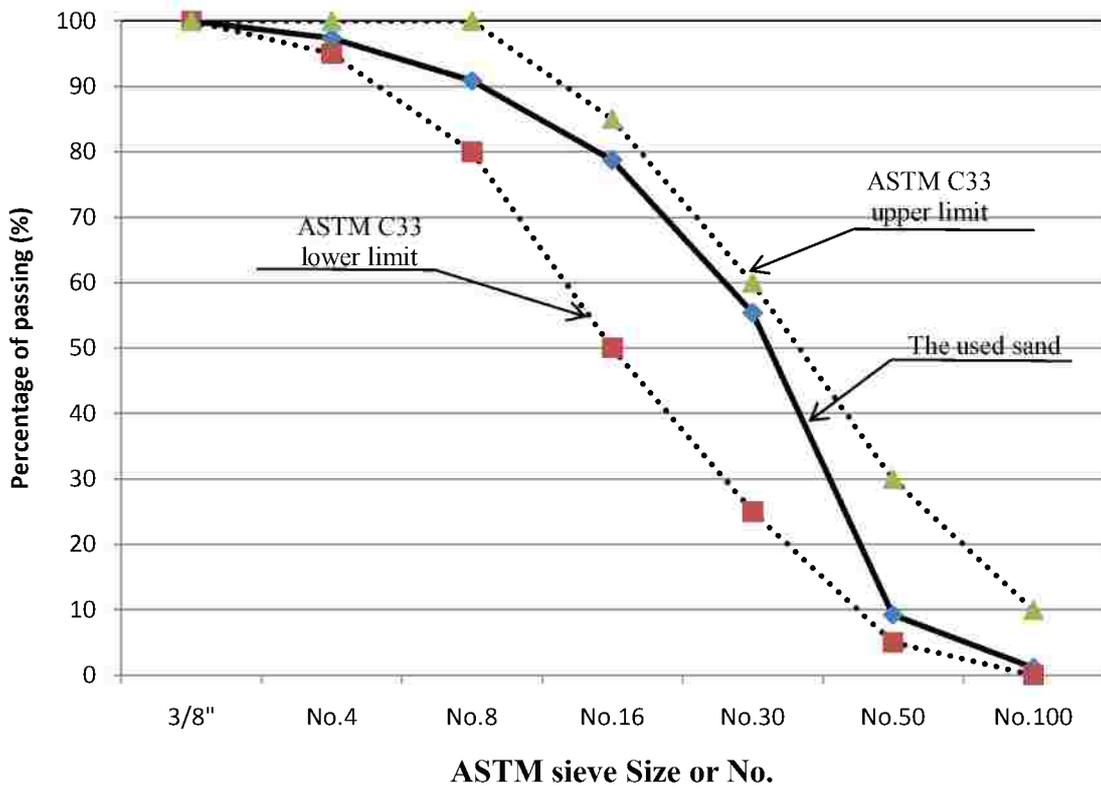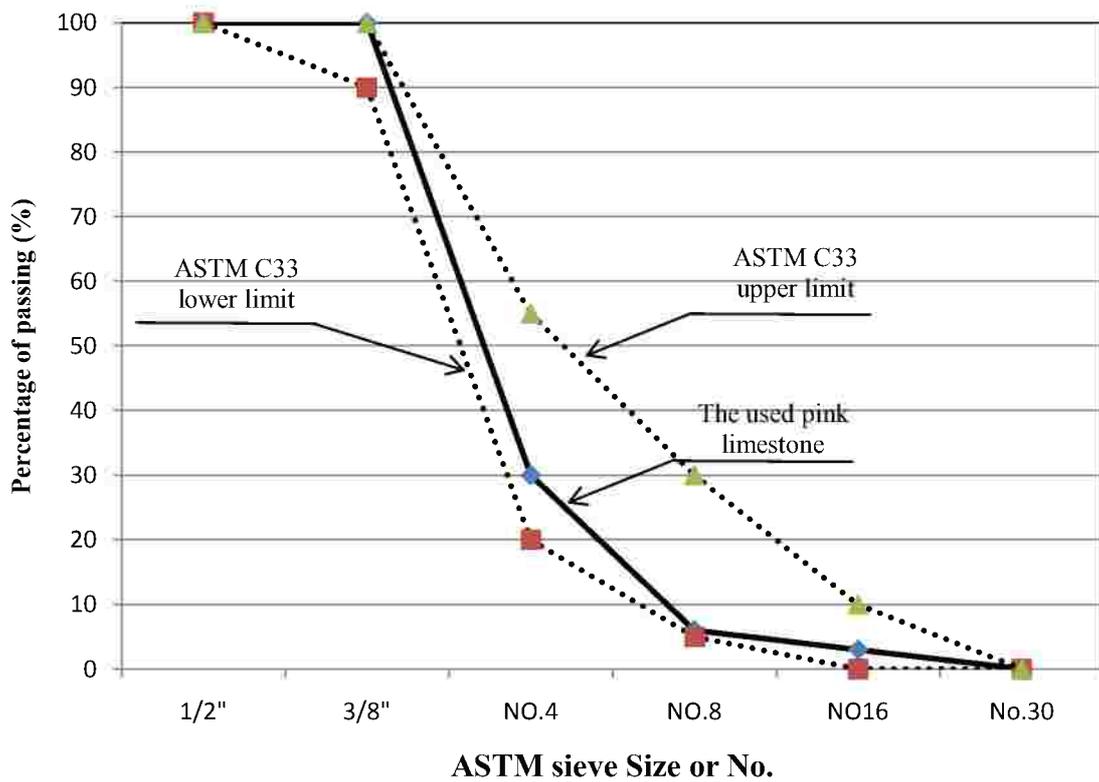| Property	Natural Aggregate		Limits (According to Egyptian standard specifications)
	Coarse Agg. Crushed pink limestone (N.M.S = 3/8")	Fine Agg. Sand	
Specific gravity (SSD)	2.57	2.65	
Water absorption (%)	1.92	1	≤ 2.5 for coarse agg. and ≤ 2.0 for fine agg.
Materials finer than 200 sieve by washing (%)	1.4	2.5	≤ 3.0
Fineness modulus	-	2.67	

Figure 3.1 The sieve analysis of sand

Figure 3.2 The sieve analysis of pink limestone

3.2.1.3.   Rubber

Three different types of rubber particles were used in this study. The first type is 4mm crumb rubber and the other two types are fibrous rubber. The specific gravity of the used rubber particles is 1.09.

a)   Crumb rubber

Crumb rubber is produced using the mechanical shredding. As illustrated in the literature, used tired are shredded and grinded. Through this process, the metals and textile fibers are separated from rubber. The crumb rubber used in this investigation was obtained from a local company. The particles are granular in shape with a maximum nominal size 4mm, as shown in Figure 3.3. The sieve analysis of the used crumb rubber is shown in Table 3.3.

b)   Fibrous rubber

The reason for using rubber fibers is that the addition of fibers (steel, glass, carbon and polypropylene) to concrete has resulted in more ductile behavior and less plastic shrinkage cracking. Also, fibrous rubber is a by-product from tires retreading processes, so the cost is less than crumb rubber.

The rubber fibers used in this study were obtained from local company. The rubber was received in bulk and separated into different sizes by sieving through standard sieves, as shown in Figure 3.4.

Figure 3.3 4mm Crumb rubber

Table 3.3 Sieve analysis of used crumb rubber

ASTM sieve Size or No.	Percentage passing by weight %
	4mm Crumb rubber
No.4	100
No.8	21.23
No16	0.49
No.30	0.22

-   Choosing the fiber size

Trials were conducted using each size separately and the combination of different sizes as an addition to concrete at low volume fractions. It was found that the best rubberized concrete strength is given by two types of rubber fibers. These two types are named Fiber 8 and Fiber 4 according to fiber size. Rubber fiber that passed through 2.36 mm (No.8) sieve and retained on 1.18 mm (No.16) sieve is called Fiber 8, while the rubber fiber that passed through 4.75 mm (No.4) sieve and retained on 2.36 mm (No.8) sieve is called Fiber 4, as shown in Figure 3.5.
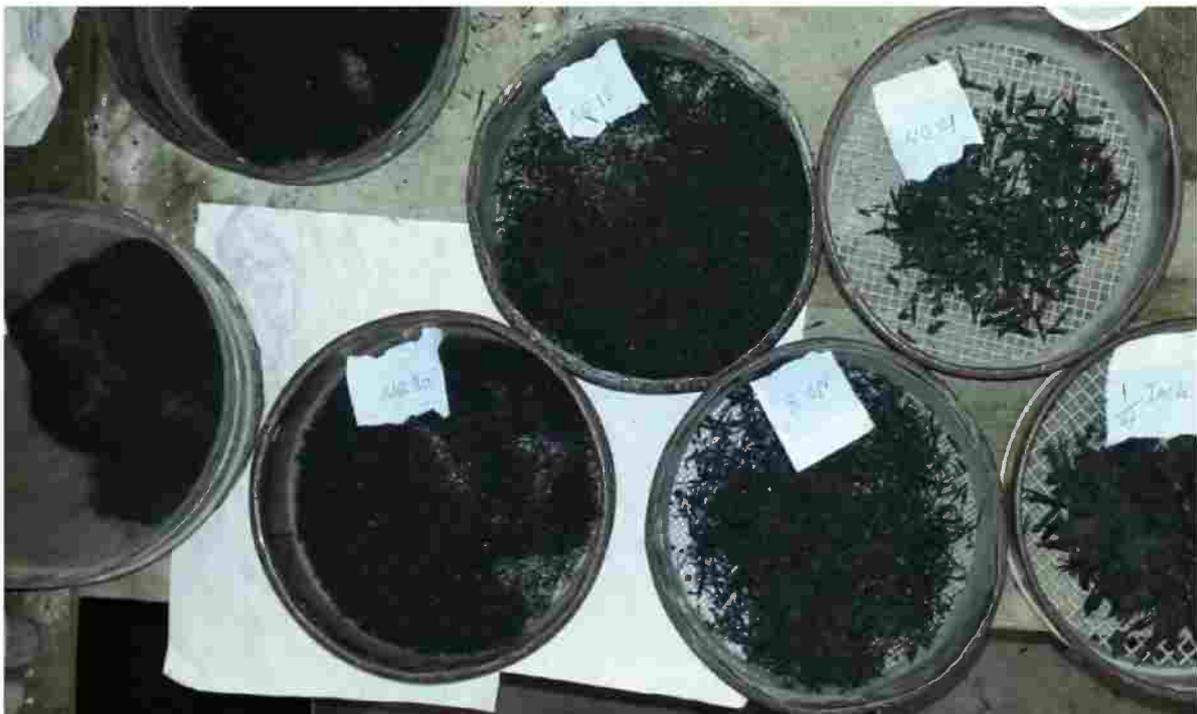

Figure 3.4 Fibrous rubber separated into different sizes

a) Fiber 8

b) Fiber 4

Figure 3.5 Fibrous rubber used in the study

- **Surface treatment of rubber particles**

Two types of surface treatment of rubber particles are used to enhance the interface interaction between rubber particles and cement matrix. The first type of treatment is by soaking rubber particles in 10% concentration of NaOH solution for 30 minutes, then washing under clean water for 5 minutes. The second type of treatment is by mixing the rubber particles with polyvinyl acetate (PVA) for 30 minutes just before adding to the cementitious materials.

3.2.1.4. Additives

Micro-silica-fume, which meets the requirement of ASTM C1240/2000, has been used as 10% replacement of cement weight. Polypropylene fiber (0.2 % by volume) has also been used as an additive to concrete in this study.

3.2.2. Mixing Procedures and Curing

It has been decided to use rubber particles as additives to concrete at low volume fraction to eliminate the loss on strength. In all mixes, except for control, the rubber particles were added to the cementitious materials before adding to the mixer. The mixer used was a pan-type roller, 0.15 cubic meter capacity. The dry aggregates were allowed to mix in for about 2 minutes, and then the rubber particles and cement were added. Finally, water was added gradually while mixing for about more 5 minutes. This mixing procedure for rubberized concrete is recommended by M. M. Balaha [19] and Gideon Momanyi Siringi [11]. The mixture was charged out from the mixer. Then specimens were cast into moulds and compacted using vibrating table. After demolding, all specimens were submerged into water tank at 20° C until time of testing.

3.2.3. Test Parameters

3.2.3.1. Experimental factor levels

Five factors each at three levels were considered in this study, as shown in Table 3.4. Three concrete grades (C20, C25 and C30), three rubber volume fractions as an additive to concrete (0.5%, 1.5% and 2.5%), three types of additives (without , polypropylene fiber 0.2% and 10% silica fume as cement replacement by weight), Three types of rubber particles (4mm granules and two types of rubber fibers with different aspect ratios) and Three types of surface treatments for rubber particles (rubber treated with NaOH solution, Plain rubber and rubber treated with PVA).

The factors levels were selected to study the effect of rubber type, volume fraction and surface treatment with different concrete grades. Silica fume was used to improve rubber-paste bond, while polypropylene fiber were used to improve toughness especially with crumb rubber.

3.2.3.2. Experimental program

Three mixes were performed as control with three concrete grades (C20, C25 and C30) without using any rubber or additives. Twenty seven mixes were performed and five factors were considered. Fractional factorial method of experimentation was considered to organize the tested variables and to analysis the test results. The 27 mixes presented in Table 3.5 are 1/9 replicate fractional factorial of 3^5 design based on the Principle Block [53-56].

Table 3.6 shows the mix proportions of the control mixes and the other 27 mixes including rubber and additives

Table 3.4 Factors and factor levels

Factor description	Factor levels	Factor Value
A (Concrete grade)	0	C20
	1	C25
	2	C30
B (Rubber %)	0	0.5%
	1	1.5%
	2	2.5%
C (Additives)	0	None
	1	Polyp. 0.2%
	2	S.F 10%
D (Rubber Type)	0	Crumb 4mm
	1	Fiber 8
	2	Fiber 4
E (Rubber surface treatment)	0	NaOH
	1	Without
	2	PVA

3.2.4. Testing

Six series of tests were conducted to determine compressive strength, slump, elastic modulus, impact resistance, toughness and abrasion resistance of rubberized concrete. Table 3.7 presents the relevant specifications and specimens' dimensions for each test.

Drop weight test

According to ACI 544.2 R 89, drop weight test can be used to evaluate the impact resistance of concrete. The test can be used to compare the relative advantages of different fiber-concrete mixtures and to demonstrate the improved performance of Fiber reinforced concrete compared to conventional concrete. Thus, the test was used in this study to evaluate the improvement in impact resistance of rubberized concrete comparing to normal concrete. For this test, cylinders of 150 x 300 (diameter x length) were cast and then samples were prepared by cutting to 63.5 mm thickness to be used in the drop weight test, as shown in Figure 3.6.

Figure 3.6 Drop weight test equipment

Table 3.5 Factors levels and values of the 1/9 replicate fractional factorial of 3^5 design based on the Principle Block.

Mix No	Factor level					Factor description				
	A	B	C	D	E	A (Concrete grade)	B (Rubber %)	C (Additives)	D (Rubber Type)	E (Rubber surface treatment)
1	0	0	0	0	0		0.50%	None	Crumb 4mm	NaOH
2	0	1	1	0	2		1.50%	PolyP 0.2%	Crumb 4mm	PVA
3	0	2	2	0	1		2.50%	S.F 10%	Crumb 4mm	Plain
4	0	0	2	1	1		0.50%	S.F 10%	Fiber 8	Plain
5	0	1	0	1	0	C20	1.50%	None	Fiber 8	NaOH
6	0	2	1	1	2		2.50%	Polyp 0.2%	Fiber 8	PVA
7	0	0	1	2	2		0.50%	Polyp 0.2%	Fiber 4	PVA
8	0	1	2	2	1		1.50%	S.F 10%	Fiber 4	Plain
9	0	2	0	2	0		2.50%	None	Fiber 4	NaOH
10	1	0	2	0	2		0.50%	S.F 10%	Crumb 4mm	PVA
11	1	1	0	0	1		1.50%	None	Crumb 4mm	Plain
12	1	2	1	0	0		2.50%	Polyp 0.2%	Crumb 4mm	NaOH
13	1	0	1	1	0		0.50%	Polyp 0.2%	Fiber 8	NaOH
14	1	1	2	1	2	C25	1.50%	S.F 10%	Fiber 8	PVA
15	1	2	0	1	1		2.50%	None	Fiber 8	Plain
16	1	0	0	2	1		0.50%	None	Fiber 4	Plain
17	1	1	1	2	0		1.50%	Polyp 0.2%	Fiber 4	NaOH
18	1	2	2	2	2		2.50%	S.F 10%	Fiber 4	PVA
19	2	0	1	0	1		0.50%	Polyp 0.2%	Crumb 4mm	Plain
20	2	1	2	0	0		1.50%	S.F 10%	Crumb 4mm	NaOH
21	2	2	0	0	2		2.50%	None	Crumb 4mm	PVA
22	2	0	0	1	2		0.50%	None	Fiber 8	PVA
23	2	1	1	1	1	C30	1.50%	Polyp 0.2%	Fiber 8	Plain
24	2	2	2	1	0		2.50%	S.F 10%	Fiber 8	NaOH
25	2	0	2	2	0		0.50%	S.F 10%	Fiber 4	NaOH
26	2	1	0	2	2		1.50%	None	Fiber 4	PVA
27	2	2	1	2	1		2.50%	Polyp 0.2%	Fiber 4	Plain

Table 3.6 Mix composition /m³ for rubberized concrete and control

Mix No	Cement (kg)	W/c	Water (liter)	Coarse Agg (kg)	Fine Agg (kg)	Rubber (kg)	Rubber Vf%	Rubber type	Treatment	S.F (kg)	Polyp. (kg)
1	250	0.70	175	1156	771	5.45	0.5%	Crumb 4mm	NaOH	-	-
2	250	0.70	175	1140	760	16.35	1.5%	Crumb 4mm	PVA	-	1.8
3	225	0.70	175	1125	750	27.25	2.5%	Crumb 4mm	Without	25	-
4	225	0.70	175	1156	771	5.45	0.5%	Fiber 8	Without	25	-
5	250	0.70	175	1140	760	16.35	1.5%	Fiber 8	NaOH	-	-
6	250	0.70	175	1125	750	27.25	2.5%	Fiber 8	PVA	-	1.8
7	250	0.70	175	1156	771	5.45	0.5%	Fiber 4	PVA	-	1.8
8	225	0.70	175	1140	760	16.35	1.5%	Fiber 4	Without	25	-
9	250	0.70	175	1125	750	27.25	2.5%	Fiber 4	NaOH	-	-
10	270	0.58	175	1131	754	5.45	0.5%	Crumb 4mm	PVA	30	-
11	300	0.58	175	1116	744	16.35	1.5%	Crumb 4mm	Without	-	-
12	300	0.58	175	1100	733	27.25	2.5%	Crumb 4mm	NaOH	-	1.8
13	300	0.58	175	1131	754	5.45	0.5%	Fiber 8	NaOH	-	1.8
14	270	0.58	175	1116	744	16.35	1.5%	Fiber 8	PVA	30	-
15	300	0.58	175	1100	733	27.25	2.5%	Fiber 8	Without	-	-
16	300	0.58	175	1131	754	5.45	0.5%	Fiber 4	Without	-	-
17	300	0.58	175	1116	744	16.35	1.5%	Fiber 4	NaOH	-	1.8
18	270	0.58	175	1100	733	27.25	2.5%	Fiber 4	PVA	30	-
19	350	0.50	175	1106	738	5.45	0.5%	Crumb 4mm	Without	-	1.8
20	315	0.50	175	1091	727	16.35	1.5%	Crumb 4mm	NaOH	35	-
21	350	0.50	175	1075	717	27.25	2.5%	Crumb 4mm	PVA	-	-
22	350	0.50	175	1106	738	5.45	0.5%	Fiber 8	PVA	-	-
23	350	0.50	175	1091	727	16.35	1.5%	Fiber 8	Without	-	1.8
24	315	0.50	175	1075	717	27.25	2.5%	Fiber 8	NaOH	35	-
25	315	0.50	175	1106	738	5.45	0.5%	Fiber 4	NaOH	35	-
26	350	0.50	175	1091	727	16.35	1.5%	Fiber 4	PVA	-	-
27	350	0.50	175	1075	717	27.25	2.5%	Fiber 4	Without	-	1.8
C20	250	0.70	175	1164	776	-	-	-	-	-	-
C25	300	0.58	175	1139	759	-	-	-	-	-	-
C30	350	0.50	175	1114	743	-	-	-	-	-	-

Table 3.7 Summary of the tests performed and the relevant standards.

Properties	Specifications	Specimen dimensions	Age of testing
Compressive strength	BS 1881: Part 3	Cubes 100x100x100 mm	7, 28 days
Slump	ASTM C 143		
Static Elastic modulus	ASTM C 469	Cylinder D=150 mm and L = 300 mm	28 days
Impact resistance	ASTM D 1557 ACI 544.2 R 89	Cylinder D = 150 mm and L = 63.5 mm	28 days
Flexural toughness	ASTM C1609	Beams 350*100*100 mm	28 days
Abrasion	ASTM 418	Cubes 70*70*70 mm	28 days

Flexural toughness

For evaluation of flexural toughness, the ASTM Standard C 1609 replaces its predecessor ASTM Standard C1018-97. ASTM C1609 Standard recommends estimating toughness as the energy equivalent to the area under load–deflection curve up to a net deflection of 1/150 of the span. The parameters calculated for the determination of flexural toughness according to ASTM C 1609 are shown in Figure 3.7.
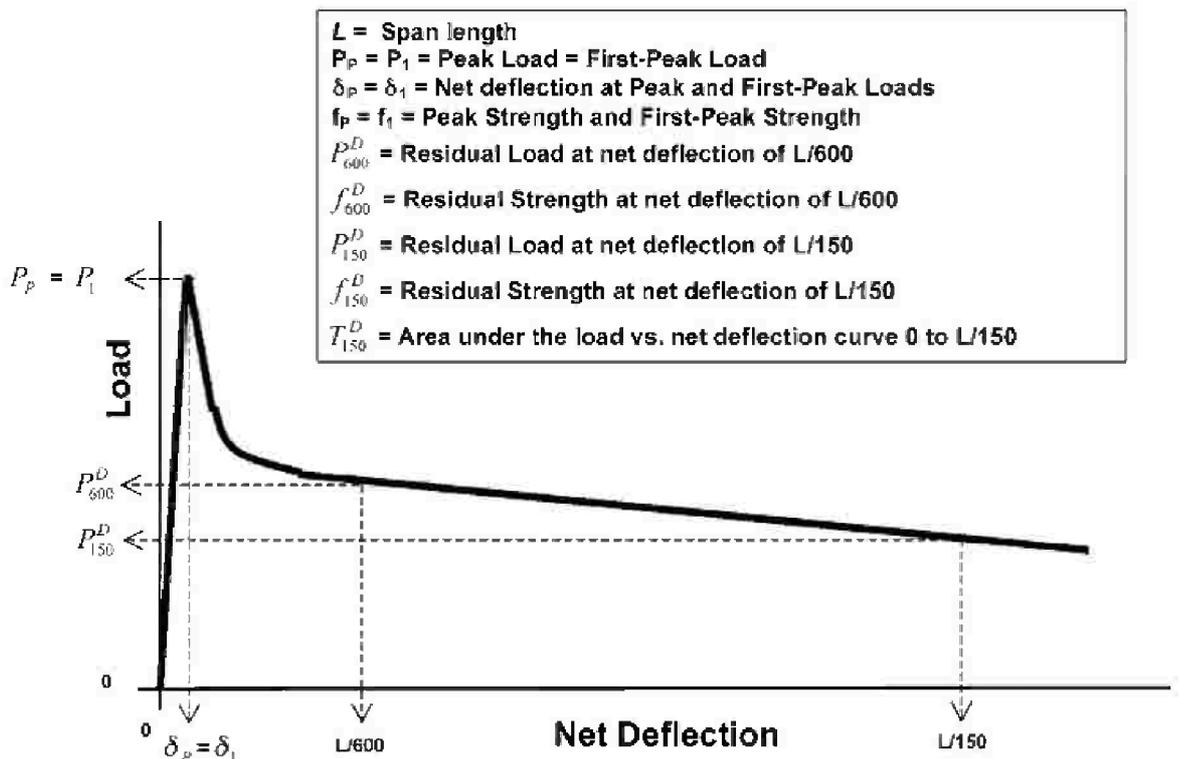
Figure 3.7 Parameters calculated for evaluation of flexural toughness

Three specimens were tested for each mix with dimensions of 350*100*100mm in toughness test. Dial gauge, with an accuracy of 0.01 mm, was used to determine the net deflection at the mid-span of the tested specimens. The dial gauge was attached to the tested specimens using a metal frame to eliminate the effects of seating or twisting of the specimen on its supports, as shown in Figure 3.8.

Figure 3.8 Arrangement of specimen for Flexural toughness test

3.3. RUBBERIZED CONCRETE AT HIGH VOLUME FRACTIONS AND RUBBER-BINDER COMPOSITES (SECTION TWO)

The focus in this section is to study the availability of using waste rubber particles in non-structural building products. Rubber is recognized as a high insulator material. Also, from the previous investigations, the implementation of waste rubber particles in concrete has a negative effect on most mechanical properties. This study aims to benefit from the high insulation properties of rubber to enhance the thermal and acoustical insulation properties of concrete. Also, the properties of rubber-cement and rubber-epoxy composites were studied in this investigation, especially in terms of thermal and acoustical insulation. The concept in these composites is to use cement or epoxy as a binder of the waste rubber particles with any other additives.

The experimental program is divided into two parts. The first part focuses on the thermal and acoustical insulation properties of rubberized concrete at high rubber volume fractions. Also, the physical and mechanical properties of rubberized concrete were evaluated in terms of density, absorption, compressive strength, impact resistance, ductility and flexural strength. The second part is about the rubber-cement and rubber epoxy composites. Series of tests were conducted to determine the thermal and acoustical insulation properties in addition to stress-strain relations and the related properties for these composites.

3.3.1. Materials Properties

3.3.1.1. Rubberized concrete

Type I Ordinary Portland cement according to ASTM C 150 was used in this research for all mixes. Natural siliceous sand and pink limestone of 3/8 inch nominal maximum size, were used as natural aggregates. Also, high range water reducer admixture Type F (synthetic polymers base) was used in the mixtures. The same cement, sand and crushed pink limestone used in section one is also used in section two.

Crumb rubber was used as a replacement of sand by volume. It was decided to use crumb rubber with the same gradation as natural sand. Three different sizes of rubber particles were used to provide that gradation. ASTM sieve No. 40 (0.42mm), ASTM sieve No.20 (1mm) and 2mm rubber particles were mixes in portion 1:1:1. The physical properties and sieve analysis of the used crumb rubber is shown in Tables 3.8 and 3.9.

Table 3.8 Properties of rubber used in rubberized concrete

Specific gravity (SSD)	Fineness modulus			
	0.42mm crumb	1mm crumb	2mm crumb	Crumb rubber (all sizes combined)
1.09	1.8	2.9	4.3	3

Table 3.9 Sieve analysis of rubber used in rubberized concrete

ASTM sieve size or No.	Percentage passing by weight %				Limits according to ASTM C33-01 for fine Agg
	0.42mm crumb	1mm crumb	2mm crumb	Crumb rubber (all sizes combined)	
3/8"	100	100.0	100.0	100.0	100
NO.4	100.0	100.0	100.0	100.0	95-100
NO.8	100.0	100.0	67.5	89.2	80-100
NO16	100.0	87.4	3.8	63.7	50-85
No.30	94.0	19.4	0.3	37.9	25-60
No.50	20.5	2.9	0.2	7.9	5-30
No.100	2.4	0.3	0.1	0.9	0-10

3.3.1.2. Rubber-cement and Rubber-epoxy composites

The same types of rubber particles used in section one are also presented in this part of the investigation as shown in Fig 3.9. Rubber particles were exposed to surface treatment to enhance the interface interaction between rubber particles and the used binder. The rubber particles were treated with polyvinyl acetate (PVA) or 30 minutes just before mixing with the binder [19].

Type I Ordinary Portland cement according to ASTM C 150 was used in the Rubber-cement composites as a binder material. For Rubber-epoxy composites, polyurethane epoxy resin was used in this study as an adhesion, which complies with BS EN 12004, ES 4118. This epoxy is a solvent free and slow drying adhesive. The physical properties of the used polyurethane epoxy are shown in Table 3.10.

a) Crumb rubber	b) Fiber 8

c) Fiber 4

Figure 3.9 Types of rubber particles

Table 3.10 The physical properties of the used polyurethane epoxy.

Property[*]	
Density	1.46 t/m^3
Pot life	60 minutes
Final setting time	48 hours
Full hardness	7 days
Color	Beige

* As given from the technical data sheet provided by the producer.

3.3.2.Mixing Proportions

3.3.2.1. Rubberized concrete

Crumb rubber was used as a replacement of fine aggregate by volume, the replacement levels were 0%, 20%, 40%, 60%, 80% and 100%. Table 3.11 presents the mix composition for control mix and rubberized concrete mixes per cubic meter. The All mixtures were set to achieve a constant slump (20 ± 5mm) using different dosages of Type F super-plasticizing admixture (synthetic polymers base). The water-cement ratio of 0.45 was kept constant for all mixes.

3.3.2.2. Rubber-cement and Rubber-epoxy composites

For the Rubber-cement composites, water-cement ratio was kept constant at 0.30 for all mixes. Cement was mixed with water first for about 1 minute, and then the rubber particles were added gradually to the cement paste. The mixing time extended to 2 minutes after adding all constituents. It was notices that Fiber 8-cement composites obtained low workability comparing to that of crumb rubber and Fiber 4. This behavior could be attributed to the large surface area of Fiber 8 particles.

For the Rubber-epoxy composites, the rubber: epoxy ratio was kept constant at 1:3, respectively, for all mixes. The two components of the used epoxy were mixed thoroughly for a period of 2 minutes using a slow rotating electric mixer, then the rubber particles were added gradually while mixing continued another 2 minutes.

Table 3.11 Mix composition for control mix and rubberized concrete mixes per cubic meter

Mix No	Rubber Content%	Cement (kg)	W/c	Water (liter)	Coarse Agg (kg)	Fine Agg (kg)	Rubber (kg)
1	0%	400	0.45	180	1050.0	705.0	0.0
2	20%	400	0.45	180	1050.0	564.0	58.0
3	40%	400	0.45	180	1050.0	423.0	116.0
4	60%	400	0.45	180	1050.0	282.0	174.0
5	80%	400	0.45	180	1050.0	141.0	232.0
6	100%	400	0.45	180	1050.0	0.0	290.0

3.3.3. Testing

Series of tests were conducted to determine the thermal and acoustical insulation properties in addition to the mechanical properties of rubberized concrete and rubber-binder composites. Tables 3.12 and 3.13 present the relevant specifications and specimens' dimensions for each test. Samples of rubberized concrete and Rubber-cement composites were cured in water at 20° C for 28 days. As for Rubber-epoxy, samples was cured in air at ambient temperature 25° C.

Table 3.12 Summary of the tests performed on rubberized concrete and the relevant standards.

Property	Specifications	Specimen dimensions	Age of testing
Thermal conductivity	Ref [57,58]	Cylinder D = 75 mm and L = 30 mm	28 days
Sound Attenuation	Ref [59,60]	Cylinder D = 150 mm and L = 30 mm	28 days
Compressive strength	BS 1881: Part 3	Cubes 150x150x150 mm	7, 14,28 days
Density and absorption	ASTM C 469	Cubes 70x70x70 mm	28 days
Impact resistance	ASTM D 1557 ACI 544.2 R 89	Cylinder D = 150 mm and L = 63.5 mm	28 days
Flexural strength	ASTM C78	Beams 350*100*100 mm	28 days

Table 3.13 Summary of the tests performed on Rubber-cement and Rubber-epoxy composites and the relevant standards.

Properties	Specifications	Specimen dimensions	Age of testing
Thermal conductivity	Ref [57,58]	Cylinder D = 75 mm and L = 30 mm	28 days
Sound Attenuation	Ref [59,60]	Cylinder D = 75 mm and L = 30 mm	28 days
Compressive strength	ASTM D1621	Cylinder D=75 mm and L = 150 mm	28 days

3.3.3.1. Thermal conductivity

Lee's method of a bad conductor was used to determine the thermal conductivity of rubberized concrete and Rubber-cement composites. Thermal conductivity, k, is a material property of a material that indicates its ability to conduct heat. Conduction will take place if there is a temperature gradient in a solid medium. Energy is transferred from more energetic to less energetic molecules when neighboring molecules collide. Conductive heat flow occurs in direction of the decreasing temperature because higher temperature is associated with higher molecular energy. Fourier's Law expresses conductive heat transfer as:

$$K = \frac{Q*x}{A\ (T1-T2)} \quad \text{................Eq. 3.1}$$

Where;

Q is the steady state rate of heat transfer,
K is the thermal conductivity of the sample (W/m.C),
A is the cross sectional area (mm^2),
x is the thickness of the sample (mm) and
(T 1 – T2) is the temperature difference across the sample thickness (^{o}C)

Fig 3.10 illustrates the temperature gradient through the sample. The evaluation of thermal conductivity is based on assuming that the heat loss from the sides of the sample is negligible. Thus, to keep the loss from the sides small, the sides of samples were isolated using glass wool sheets. The sample was made in form of a disk with 75 mm diameter and 30 mm thickness.
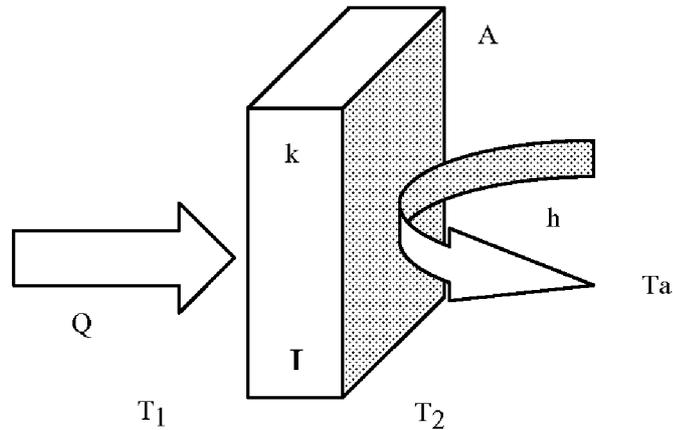

Fig 3.10 The temperature gradient through the sample

Fig 3.11 shows the configuration of Lee test of bad conductors. Rubberized concrete specimen of Lee test is shown in Fig 3.12. The device consists of two brass discs and there is a steam heater source to cause a heat gradients and the specimen is positioned between the brass discs. Two thermometers T1 and T2 were inserted into two holes in the brass discs to evaluate the temperature gradient. The test continued until reach the thermal equilibrium where T2 is constant for more than 10 minutes (the steady stated of heat transfer).

To determine the heat transfer Q, the steam chamber was removed and the temperature reduction in the brass disc is recorded through time up to (T1 − 10 o C). The relation between temperature and time is plotted and the slope is determined as$\left(\frac{dT}{dt}\right)$, as seen in Fig 3.13. The value of Q can be determined as;

$$Q = mh\left(\frac{dT}{dt}\right) \quad \text{..................Eq. 3.2}$$

Where;

m is the mass of the brass disk (gm)

h is the specific heat of brass = 0.380 J/gm. $^{\circ}$C.

dT is the temperature reduction from T_2 to T_2-10 through time dt

Fig 3.11 Configuration of Lee test of bad conductors

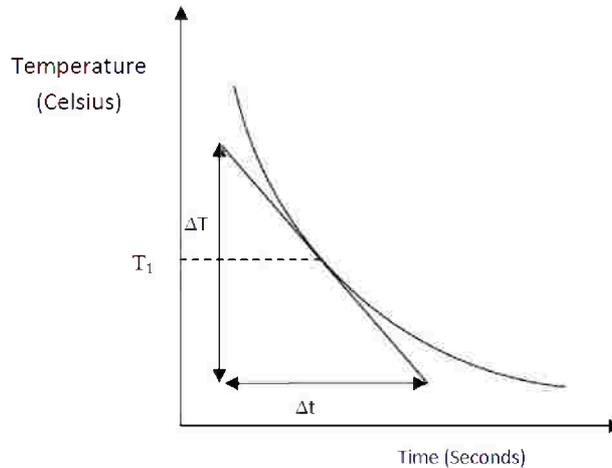**Fig 3.12 Rubberized concrete specimen of Lee test**

Fig 3.13 The temperature - time relation for calculation of Q

3.3.3.2. Sound attenuation coefficient

The sound attenuation coefficient is determined by measuring the reduction in amplitude of an acoustic wave. Sound waves propagate through material by the combined effect of scattering and absorption. Attenuation is generally proportional to the amplitude change of decaying plane wave. The configuration of the test is shown in Fig 3.14. The test consists of a wave form generator board, two sensors, amplifier and oscilloscope. The sensors are mounted directly on the specimen surface and acoustic coupling is enhanced by a layer of roller bearing grease. The amplitude of the electric input signal was held constant throughout the experimental series, changes in the amplitude can be attributed directly to the attenuating behavior of the material.

The attenuation coefficient is determined by measuring the reduction in amplitude of an acoustic wave, which has traveled for a known distance through a material and is given by the equation;

$$\alpha = -\left(\frac{20}{x}\right) \log \left(\frac{Ax}{Ao}\right) \dots\dots\dots\dots\text{Eq. 3.3}$$

Where;
A_0 is the initial amplitude of the wave and,
A_X is the amplitude after it has traveled for the distance X.

The output wave amplitude (A_X) is the absolute peak voltage of the received signal, while the amplitude of the pulse entering the specimen was measured separately on a face-to-face configuration of the transducers. The difference of amplitudes of the sent and received pulse signals, though cannot provide an absolute measure of signal transmission, it gives an indication of the signal attenuation through the thickness of the specimen.
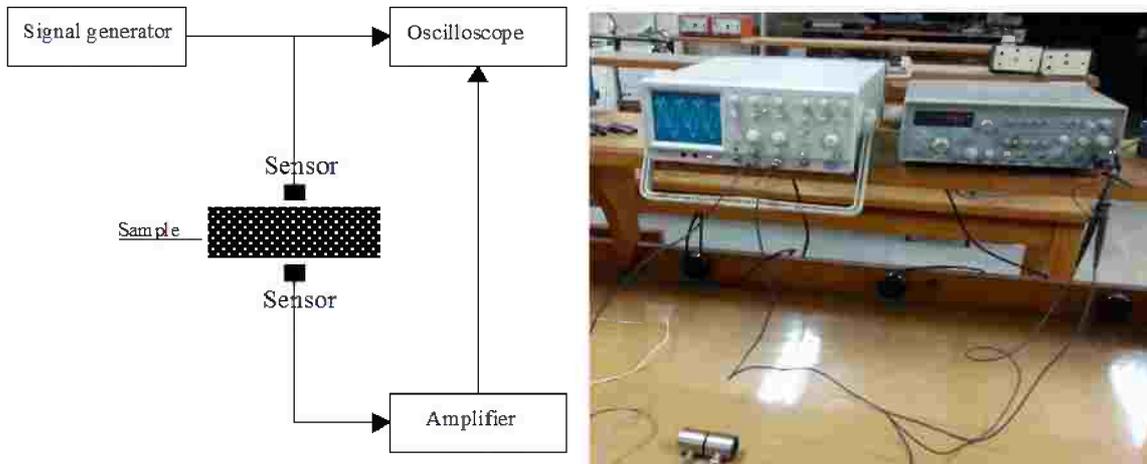
Fig 3.14 Configuration of sound attenuation test

3.3.3.3. Physical and mechanical properties

Series of tests were conducted to determine the mechanical properties of rubberized concrete, rubber-cement composites and rubber-epoxy composites, as seen in Tables 8 and 9. For rubberized concrete, compressive strength, density, absorption, impact resistance and flexural strength were studied. Drop weight test was conducted to study the effect of rubber volume fraction on impact resistance of rubberized concrete. For rubber- cement and rubber-epoxy composites, the stress-strain relations and the related properties were also conducted.