Effect of sustainable materials on concrete

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Abstract- Rubber is produced excessively worldwide every year. It cannot be discharged off easily in the environment as its decomposition takes much time and also produces environmental pollution. In such a case the reuse of rubber would be a better choice. Also, concrete is brittle and weak in tensile but strong in compressive strength. To improve concrete weakness, waste rubber is added as reinforcement. This paper reviews the state of the impact resistance of ordinary concretes containing waste rubber. It will address the impact test method that is currently available as well as some concerns about them based on extensive literature reviews. Also, the impact resistance is a very important parameter for evaluating the dynamic performance of concrete, and thus it is very necessary to study concrete under impact load. While this research on the other side will focus on the study of the resistance of concrete by improving the properties of hardened concrete using some types of pozzolanic materials. The analyses will do study properties concrete, like, workability, compressive strength, splitting tensile strength, flexural strength, unit weight. Moreover, impact strength, in particular, drop-weight impact test according to ACI 544. This test yields the number of blows necessary to cause prescribed levels of damage in the test specimen. The number of blows recorded serves as a qualitative estimate of the energy absorbed by the specimen at the levels of distress specified. The relative impact resistances of various materials can easily be established using the repeated drop-weight impact test. As a result, it was found that rubberized concrete is durable, less ductile, has greater crack resistance but has a low compressive strength when compared with ordinary concrete. The compressive strength of rubberized concrete can be increased by adding some amount of silica fume.

Keywords – concrete, waste rubber, impact resistance, recycle.

I. Introduction

Recycling of waste tires is considered as one of the major environmental challenges faced by every country. Many countries follow the two easiest ways of disposing. First, the burning of tires and second used as a landfill because of low density and poor degradation. Nowadays, some countries do not accept the burning method because while burning the waste tires, it produces an enormous amount of smoke which will get mixed in the natural air and lead to environmental issues. The second method of landfill techniques is also not advisable because of uneven settlement and the stagnation of stormwater during the rainy season as this will produce mosquitoes that spread many diseases. Hence, this becomes a more dangerous health hazard [1]. Concrete is the most commonly used construction material in the world. As the population around the world continues to grow, so does the demand for new infrastructure [2]. Concrete comprises natural resources in the form of aggregates, and the increasing demand for concrete structures thus places a burden on the environment and the limited resources that are available. As a result, there has been a focus on developing sustainable resources within the construction industry with an emphasis on innovative and non-conventional utilization of recycled materials [3]. Plain concrete has high compressive strengths but is brittle and very weak in tensile and its flexural strength it only about 1/10 of its compressive. It was recently showed that the toughness index [4] and durability [5] of concrete is enhanced by mixing with part of the reclaimed rubber powders. Additionally, the response of concrete materials subjected to high strain rate loadings differs from that under static loadings. The strain rate effect on normal concrete has been characterized by many studies [6]. Similarly, the existing research results [7] show that the compressive strength of rubber concrete has the same strain rate effect and the energy absorption capability of rubber concrete under dynamic loadings is better than normal concrete. While the tensile strength of the concrete materials is much weaker than the compressive strength, it is a necessary property of concrete. Making concrete a ductile material would also improve the impact strength and toughness of the concrete. Another issue would be to seek ways of making the concrete “green” or environmentally friendly through the choice of materials while retaining the core advantages of the concrete. Ductility is a very desirable structural property because it allows the stress re-distribution and allows warning signs of impending failure. One material that is suggested as a potential replacement of mineral aggregates is rubber from used tires. Another significant difference is that the unit weight is much lower; therefore, tire-derived aggregates can be considered as lightweight aggregates [8]. Using crumb rubber as a replacement for mineral aggregates in concrete resulted in a vast beneficial use of tires [9]. It was noticed that there was a decrease in a slump with an increase in the rubber content; admixtures made with fine crumb rubber were more workable than those with coarse tire chips or those with a combination of tire chips and crumb rubber [10].The rubberized concrete showed possible advantages in reducing or minimizing the vibration and impact effect because of the unique elasticity properties of the rubber material [11]. As most of the literature review has shown a significant decrease in the mechanical properties of concrete after the addition of tire rubber particles as aggregates. Using only coarse rubber particles affects the properties of concrete more negatively than do only fine particles. The plastic energy capacity of the normal concrete has increased by adding rubber. For their high plastic energy capacities, concrete has shown high strains, particularly under the impact effects [12]. The purpose of aggregating rubber is to increase concrete’s flexibility, elasticity, and capacity to absorb energy. Many researchers have therefore used rubber particles as aggregates in concrete production to eliminate poor deformation capacity, low tensile strength, and improve energy absorption capacity [13]. Results from previous tests indicated that introducing rubber particles as aggregate enhanced deformation and energy absorption capacities while they decreased workability and mechanical properties [14]. Several impact tests have been used to show the relative brittleness and impact resistance of concrete and similar construction [15]. However, none of these tests has been declared to be a standard test due to the lack of statistical data on the variation of the results. In this regard, ACI Committee 544 (1996) proposed a drop-weight impact test to test the impact resistance of fibre concrete [16]. The test is widely used since it is simple and economical. However, the results got from this test are often noticeably scattered. This study aimed to provide an insight into the effect of rubber as a partial replacement of sand on the mechanical properties and impact resistance of concrete.

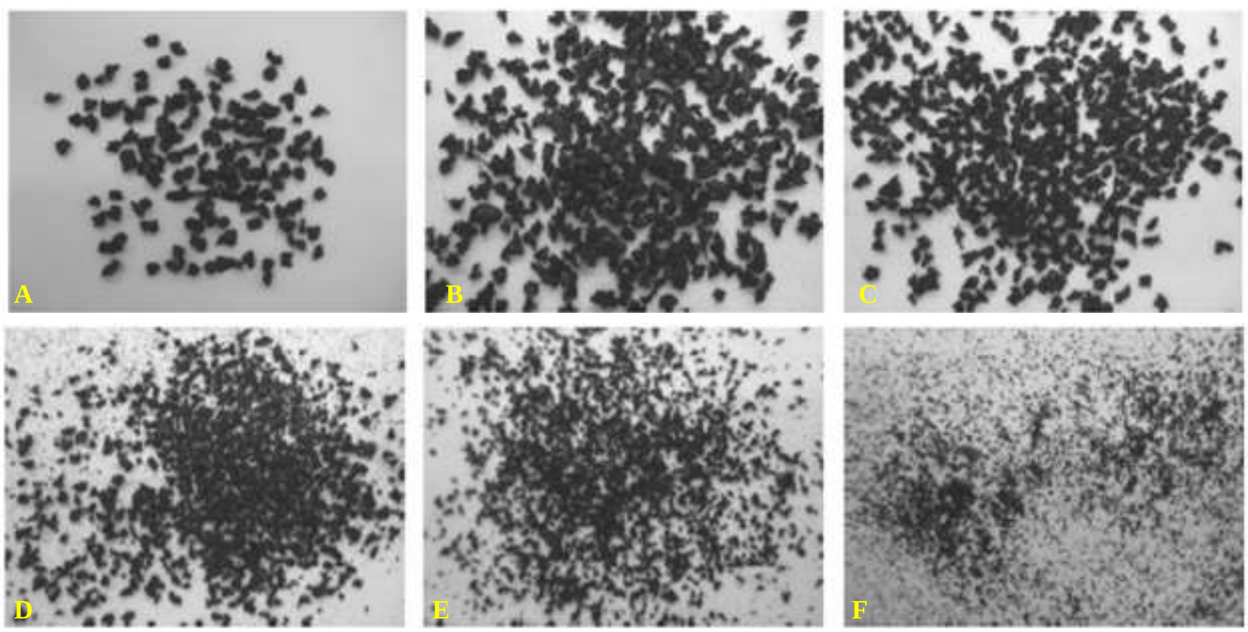

Figure 1: Classifications of rubber aggregates: (A) 4 mm, (B) 2 mm, (C) 0.9 mm, (D) 0.55 mm, (E) 0.4mm, (F) 0.2 mm [17]

II. RECYCLING OF WASTE TIRE RUBBER

The most preferred method for the recycling of tire rubber is by grinding it and then to convert it for various applications. The waste rubber used in concrete mixtures is in sizes ranging from 0.0075 mm to 4.75 mm as fine aggregate, (Fig.1). The steps involved in the production of waste rubber include shredding, separation of steel and textile, granulation, and classification, then it is cut the tires into larger pieces and then shredded into smaller pieces, then the grind it [18].

III.MECHANICAL PROPERTIES

To improve mechanical properties, several properties of rubberized concrete have been studied parameters that will review in this paper as the compressive resistance of concrete, tensile resistance, flexural resistance, and impact resistance.

3.1 The workability of concrete

The workability of concrete is the ease with which concrete can be mixed, handled, and compacted. Rubberized concrete has lower workability compared with plain concrete. The slump value of rubberized concrete decreases along with the increasing percentage or replacement of aggregates by rubber [19]. It has been observed a decrease in workability with an increase in crumb rubber grades and proportions. The reduction could be because of the reduced inter-particle friction between the rubber and other constituents [20]. Workability increases along with the high specific surface area of the concrete constituents even though a finer rubber aggregate has a higher surface area compared with a coarser rubber aggregate; therefore, a higher reduction is also observed in workability [21]. This finding is more pronounced for the high roughness of rubber aggregate. Because the rough surface of rubber aggregate causing the increasing particle friction within the concrete and reacquires more energy to flow [22]. Therefore, to obtain similar workability water requirement in rubberized concrete is higher than plain concrete. Although previous studies have proposed dosage of superplasticizers to enhance the workability of rubberized concrete [23].

3.2 The unit weight

The density of rubberized concrete is less than ordinary concrete, where, with the increase in the percentage of rubber in concrete, the density of concrete decreases [24]. The density of concrete depends upon the amount of air entrained or air entrapped, water-cement ratio, which depends upon the size of aggregates. The increase in rubber content in concrete increases the air content which decreases the density of concrete. At about 25% of the content of rubber in concrete, the density decreases to about 90% of the ordinary concrete. However, this decrease is very less when rubber content is less than 10-15% of the total aggregate volume [25]. Studied on rubberized concrete with tire chips partially replaced for coarse aggregate, crumb rubber for fine aggregate, and a combination of tire chips and crumb rubber for total mineral aggregate. It observed that the density of the concrete with coarse aggregate replacement had a reduction of 45% that of fine aggregate replacement reduced by 34% and the combination gave a reduction of 33%. [26] A comprehensive review of the applications of waste tire rubber in cement concrete.

3.3 The compressive strength

The reasons have mentioned the decrease in the compressive strength of the rubberized concrete, where the cement paste containing rubber particles would surround the aggregates. This cement paste would be much softer than that without the rubber. This results in the rapid development of cracks around the rubber particles while loading and this leads to quick failure of specimens. Also, there would be a lack of proper bonding between rubber particles and cement paste, as compared to cement paste and natural aggregates. This can lead to cracks because of the non-uniform distribution of applied stresses. Also, the compressive strength depends on the physical and mechanical properties of the constituent materials. If rubber replaces part of the materials, a reduction in strength will occur. Also, because of the low specific gravity of rubber and lack of bonding of rubber with other concrete materials, there is a tendency for the rubber to move upwards during vibration leading to higher rubber concentration at the top layer. Such a non-homogeneous concrete sample leads to reduced strengths [27]. The compressive strength of rubberized concrete is lower than natural concrete [28]. Approximately 4%–70% strength reduction was observed in concrete with rubber content of 5%–50% of natural aggregates, which may vary in size from 0.075 mm to 6 mm [29]. The overall reduction in the strength of rubberized concrete depends on the size, shape, mechanical properties, and percentage replacement level of rubber aggregate [30]. The causes of the decreasing trend of rubberized concrete compressive strength with increasing rubber content are illustrated in different ways in various studies. One of the major causes of this decreasing trend is the very low adhesion between rubber and the cement paste in concrete, as the rubber acts as a void in the concrete matrix and lowers the density of such matrix [31]. The smooth surface of the rubber causes low adhesion with cement paste. There are many of the problems in the empirical work that most of the researchers do not adhere to the design of the mix according to the code. Where most researchers who could approach the design of the concrete mix according to code could get better results, show Table.1. There is

Table.1. Shows binder content, water reducers, water to a binder, mixing ratios, resistance results and weight unit, got by some researchers with 20% rubber.

Researcher Name	Binder Kg/m3	W/B Ratio	%20 Rubber	% Water Reducer by weight of cement	Mixing ratio (Nearly)	Compressive Strength (MPa)	Unit Weight (kg/m3)
[32] Li-Jeng Hunag	190	1.5	FA*	9	1: 6.2: 2.1	3	1935
[33] Liang He	400	0.46	powder	1.2	1: 1.5: 3	25	-
[34] Shuaicheng Guo	280	0.44	FA	0.5	1: 2.21: 3.31	36	2350
[35] Giedrius Girskas	451	o.35	CA**	2.25	1: 1.95: 2:1	39.7	2286
[36] Agampodi S.M	388	0.40	powder	2.48	1: 1.7: 3.1	43.8	2300
[37] Omid Rezaifar	422	0.5	1–1.32mm	-	1: 1.9: 2.1	23.1	2083
[38] Priyanka Asutkar	438	0.5	CA	-	1: 1.35: 2.83	16.61	1880
[39] Nahla Naji Hilal	520	0.35	FA	4.4	1: 1.57: 1.57	57.5	-
[40] Nelson Flores	360	0.5	CA	-	1: 2: 3	27.71	2264
[41] Samar Raffoul	425	0.42	CA	7.6	1: 1.5: 2.36	43.2	2350
[42] Osama Youssf	400	0.5	powder	7.2	1: 2.17: 2:45	45.9	-

* Fine aggregate, ** Coarse aggregate

also, a clear inconsistency in most of the results published, although there are differences in concrete mixtures or type additive, there are constants in the work, for example, if the amount of water in the cement mixture decreased, this leads to increased resistance and vice versa. When we compare the amount of cement and the resulting resistance, the values are not constant and variable, and some of them use less cement, but it has better results. The ratio of water to cement did not differ significantly from the rest of the specific elements of resistance used by the researchers in their studies.

3.4 The tensile strength

The tensile strength of rubberized concrete is mostly affected by the size, shape, and textures of the aggregate, and the strength of concretes decreases as the volume of rubber aggregate increases [43]. The tensile strength of rubberized concrete decreases but the strain at failure increases correspondingly. Higher tensile strain at failure shows more energy absorbent mixes [44]. Tests conducted on the behaviour of rubberized concrete containing tire chips and crumb rubber as a replacement of aggregates showed a reduction in tensile strength but also showed maximum energy absorption during tensile loading [45]. Therefore, a higher rubber caused lower strength. When aggregates are replaced by chipped rubber, the reduction in the tensile strength of concrete is more than that of the rubberized concrete with powdered rubber for cement replacement [46]. Researchers previously provided several reasons for this phenomenon. The surface where rubber and cement paste comes in contact acts as a micro-crack, whereas the rubber acts as a cavity; therefore, the overall tensile strength of the rubberized concrete is lower than natural concrete [47].

3.5 The flexure strength

The flexure strength of concrete having rubber decreases by increasing the content of rubber in concrete [48]. A decrease has noticed in flexural strength when tire chips were partially replaced for coarse aggregates and also when tire powder was partially replaced for cement [49]. They have observed a larger loss in flexural strength when the coarse aggregate rather than fine aggregate was substituted by waste tire rubber particles [50]. The addition of silica fume and reduction in the water-cement ratio has enhanced the flexural strength of rubberized concrete [51]. The flexural strength of concrete containing rubber ash decreased with an increase in the percentage of rubber ash [52].

3.6 Impact load

Several parts of many types of structures are subjected to impact loads either repeatedly due to their function in the structure or accidentally. Accidental impacts can be due to the impact of falling objects or the collision of moving vehicles. The exposure of civilian or military structures to projectiles or explosive impact is another possible source of accidental impact. On the other hand, airport runways are designed to absorb repeated impacts from landing airplanes. Similarly, offshore structures are repeatedly exposed to the impact of seawater waves, and hydraulic structures like stilling basin are subjected to continuous impact of water and waterborne materials. Fibre-reinforced concrete is known for its superior tensile characteristic s and improved impact energy absorption capacity compared to normal concrete [53]. Concrete structures may be occasionally subjected to impact loads in forms of blast loading or gunfire. In the case of gunfire, when a concrete structure was struck by a bullet-type impact force, two possible damage modes were expected. The first one was a direct result of the impact force of the bullet. The second one was an indirect result caused by debris or broken pieces of concrete flying in random directions. Concrete was a brittle material and prone to cracking when subjected to load. Under impact or high rate of loading, cracks were forced to propagate at a faster rate and lead to catastrophic failure. To develop impact resistant concrete, ductility and energy absorption must be improved [54].

3.7 Drop-weight test

The ACI 544-2R introduced a simplified technique to qualitatively evaluate the impact resistance of fiber-reinforced concrete using the principles of the drop-weight test. However, the impact load is applied repeatedly on a cylindrical specimen until the specimen is cracked and fractured. Owing to its simplicity, several recent types of research used the ACI 544-2R Repeated Blows Drop Weight Impact test to evaluate the impact resistance of several types of new fibrous concretes and cementitious materials (Fig. 2). However, this test as for other test procedures has weak points. The most important weak point of the test is the high statistical dispersion [55]. ACI Committee 544-89 proposed a

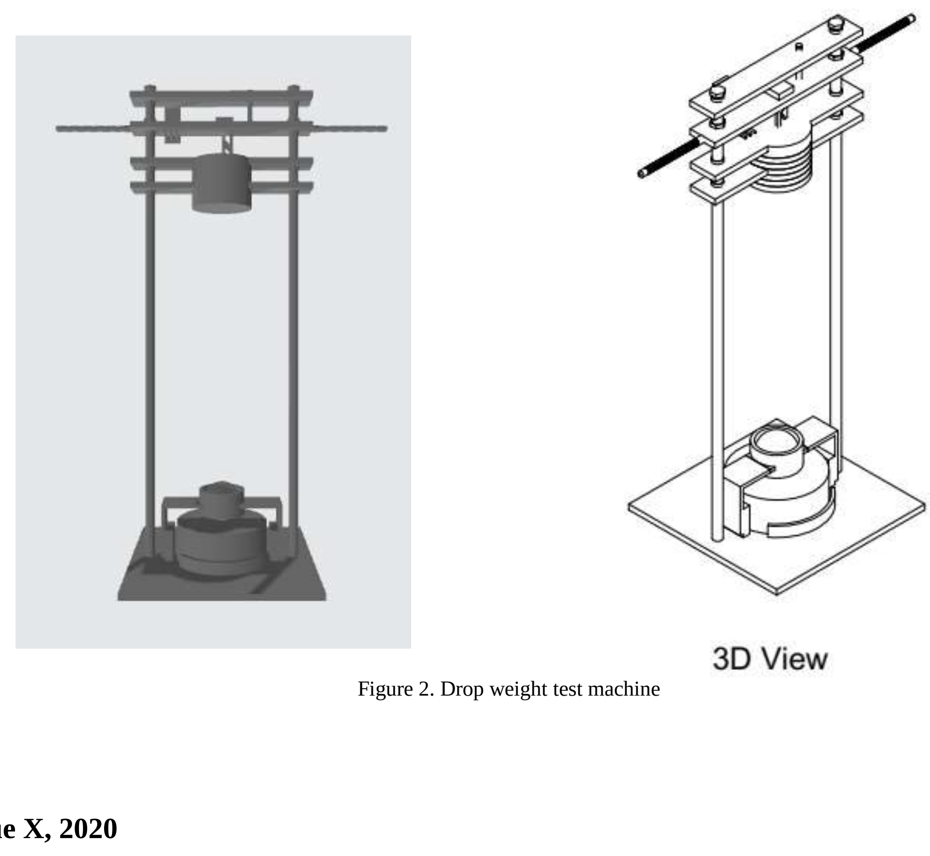

Figure 2. Drop weight test machine

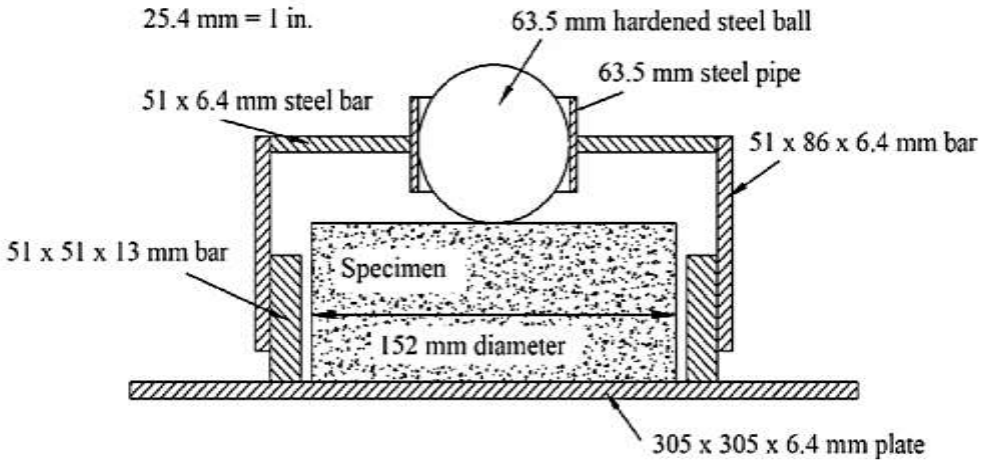

Figure 3. Drop-weight impact test

drop-weight impact test (Fig. 3) to evaluate the impact resistance of fibre concrete. This test yields the number of blows necessary to cause prescribed levels of distress in the test specimen. This number serves as a qualitative estimate of the energy absorbed by the specimen at the levels of distress specified. The equipment for the drop-weight impact test consists of: (1) a standard, manually operated 4.54 kg compaction hammer with a 457-mm drop, (2) 63.5 mm diameter hardened steel ball, and (3) a flat baseplate with positioning bracket. Besides this equipment, a mould to cast a 152 mm diameter by 63.5 mm thick ± (3mm) concrete specimens is needed. 63.5 mm thick by 152mm diameter concrete samples is made in moulds according to procedures recommended for compressive cylinders but using only one layer. The moulds can be filled partially to the 63.5 mm depth and finished, or they can be sawn from full-size cylinders to yield a specimen size of the proper thickness. Specimens cut from full-size cylinders are preferred. If fibres longer than 20 mm are used, the test should be cut from a full-size cylinder to minimize preferential fibre alignment. According to the committee, results of tests exhibit high variability and may vary considerably with the different mixtures, fibre contents, etc [56]. Many blows required for initial crack were recorded and the test was continued to record the number of blows required for complete fracture of the specimen (Fig. 4). The energy absorption capacity of each specimen is calculated using the Eq.

IE=Nmgh, *(1)*

Where

N = number of blows at the crack level,

m = mass of the dropped hammer (4.45 kg),

g = gravity due to acceleration (9.81 m/s2), and

h = drop height (4.57 m)

$Joule = kg \times m \times m/s^2 = kg \times m^2/s^2$ (*IE unit*) [56].

3.8 Impact resistance of concrete

Plain concrete is brittle with low tensile strength and this brittle characteristic increase with its strength. Conventionally, these problems are overcome by adding fibers to the concrete that exhibits ductile behaviour. Adding fiber to concrete can significantly improve the flexural strength, compressive strength, fracture toughness, ductility, and impact resistance. The impact scenario includes ship collision to the offshore platform and into bridge piers, columns in underground car parking, rock falls, and earthquakes [57]. Rubberized concrete has better

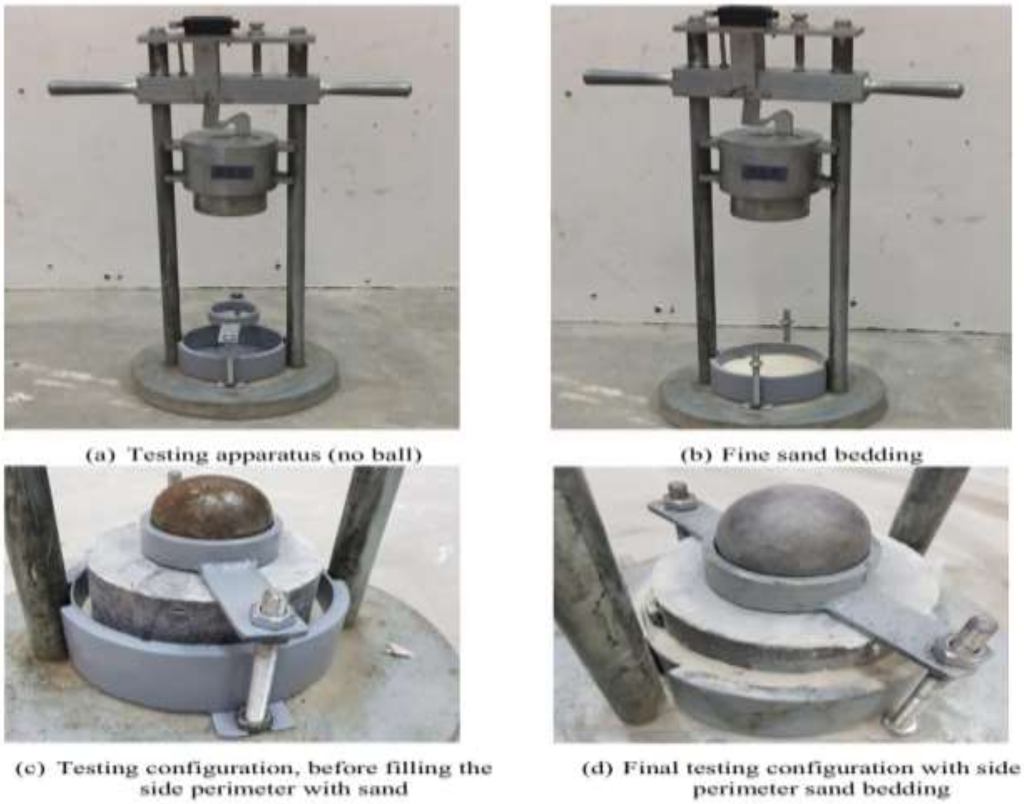

Figure 4. Impact test [58]

performance under impact loading than under static loading [59]. Rubber aggregate could absorb sudden shock because of its nature, natural aggregates cannot achieve which because of their brittle nature. Under impact force, rubberized concrete shows better resistance to crack control, because it has better ductility than normal concrete [60]. Improved impact energy was observed in rubberized concrete for the higher content of rubber by up to 50% replacement of sand [61]. The replacement of sand in concrete by 10% - 50% of waste rubber could increase impact resistance by 1.55–3.52 times compared with normal concrete [62]. The rubberized concrete sleeper helps increase the resistance to crack formation under impact loads of up to 80–110% in comparison with normal concrete. The impact strength of the rubberized concrete sleeper is almost 1.5 times that of the pre-stressed concrete sleeper when the sand replacement level is at 15% [63]. The best performance of the railway concrete sleeper is achieved with a 5% waste rubber with silica fume [64].

IV. CONCLUSIONS

Tire production is continuously increased in parallel with the economic development of the world, producing massive waste per year. Disposal and burning of waste tire have been proven as harmful for environmental safety and recycling of rubber is the most desirable alternative. The application of recycled waste tire rubber in concrete construction is an effective and sustainable process. Waste tire rubber can be utilized in concrete as a replacement of fine aggregates, coarse aggregates, and fibres. The current paper aims to review the previous studies of the influence of rubber aggregate on the mechanical properties: workability, unit weight, compressive resistance, tensile resistance, flexural resistance, impact resistance, energy absorption capacity. The general conclusions of this review are as follows:

- Waste rubber reduces concrete compressive strength, tensile strength, and flexural strength when the replacement of sand by waste rubber with different volume fractions. Compressive strength decreases with an increase in the amount of waste rubber in the mix. The addition of silica fume to plain concrete increases compressive strength. The addition of silica fume to rubberized concrete increases tensile strength and flexural strength compared with plain concrete. Accordingly, rubber content must be limited to a maximum of 15–25%, however, mechanical properties can be improved with higher cement content, lower w/b ratio.

- Increasing the amount of waste rubber in concrete leads to increase impact resistance, where rubber incorporation improves the ductility and energy absorption ability of concrete. The properties of the mix shift significantly toward those of rubber and away from those of concrete at 50–70% rubber replacement where this is when the properties of rubber control the mix. The energy dissipated by the rubberized concrete specimens at maximum load increases drastically as rubber increases. The total time of impact increase with an increase in rubber content in the mix. This increase in time shows the effectiveness of the kinetic energy dissipation of rubberized concrete. Specimens containing the rubber reduce impact severity, while maintaining much strength and resistance to fracture upon impact. The presence of waste rubber of small size in concrete increases the resistance of concrete to crack initiation under impact load. The addition of waste rubber achieves the improvement of impact properties (number of blows, impact energy, and cracking property) of normal concrete. Also, they showed it that specimens containing greater than 20% of rubber replacement reduce impact severity. Incorporating rubber content to concrete changes the failure pattern from brittle mode to ductility, where the number of cracks increases with an increase of waste rubber content, but their width and size decreased. They concluded that toughness is decreasing with the addition of crumb rubber, but adding silica fume increased it. The effect of silica fume addition on the compressive strength was more obvious from impact resistance. Utilization of these mix designs is recommended at highway applications, such as impact attenuators where energy dissipation and fracture is desired.

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