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作品名稱　ENVIRONMENTALLY FRIENDLY UPCYCLING APPROACH TO INCREASE IMPACT RESISTANCE OF REINFORCED CONCRETE STRUCTURES: USE OF INDUSTRIAL WASTE AS CONSERVATION MATERIAL

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ENVIRONMENTALLY FRIENDLY UPCYCLING APPROACH TO INCREASE IMPACT RESISTANCE OF REINFORCED CONCRETE STRUCTURES: USE OF INDUSTRIAL WASTE AS CONSERVATION MATERIAL

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Abstract

Within the scope of sustainable cities and responsible consumption, which are among the goals of sustainable development, it is aimed to contribute to life safety, defense industry, protection from disasters and economy with the new generation environmental building technologies and materials to be developed in the field of construction. It is a critical issue to protect reinforced concrete structures, piers, bridge piers, overpasses against impacts, and to reduce the damages and economic losses in disaster situations. Reinforced concrete scaffolding is the load-bearing component of the structure and its impact resistance is crucial to the overall safety of the concrete structure. Therefore, there is a need to develop technologies that can protect structures against explosion and impact loads.

Within the scope of the project, environmentally friendly and low-cost concrete materials with industrial waste glass, aluminum, plastic material additives, which can be used in columns, which are the most important part in the strength of reinforced concrete structures to prevent explosion and impact damage, were produced and their strengths were analyzed. The use and design of these materials in the strength of concrete creates the originality of the project. When the results obtained in the project were examined, it was observed that the steel fiber concretes with the addition of waste glass, aluminum ring, disc, beverage can and plastic bottle were resistant to high pressure when compared with the control groups without additives, and the change in surface height after the impact test, visual analysis and load-time graphics showed this. It is seen that the additives have a cushioning effect against the impact, absorbing the energy against the force by 87.6% and increasing the strength significantly.

In this project, where it is aimed to increase the strength of concrete structures by using the impact energy absorption feature of waste glass, plastic and aluminum, products with high added value are developed, contributing to the literature and the construction sector. With the large-scale use of the project, the costs spent on the disposal of waste materials will be reduced, the upcycling based on re-using the waste products will be contributed, and the loss of life and property due to impacts and explosions will be prevented.

Key words: Impact, Waste, Building durability, Upcycling

Aim

Within the scope of the project, it was aimed to strengthen the reinforced concrete structures against explosions and impacts by using industrial glass, plastic and aluminum wastes of different structures as concrete additives. In accordance with this purpose;

- ✓ Supply of glass, aluminum and plastic industrial wastes,
- ✓ Design and preparation of the use of glass, aluminum and plastic industrial wastes in reinforced concrete structures
- ✓ Preparation of concrete samples with waste glass, plastic bottles, aluminum rings, discs and beverage boxes designed in different structures as the control group and without additives as the experimental group.
- ✓ It was aimed to examine the burst and impact resistance of the prepared concrete samples by means of visual and mechanical tests.

1. Introduction

1.1. The importance of developing new generation building technologies and materials

Within the scope of sustainable development goals, developments in construction technology, as in all fields of science and technology, will reduce foreign dependency and increase economic development. It is aimed to contribute to human health and economy with new technologies and materials to be developed in the field of construction.

Today, there is a need to develop technologies that can protect reinforced concrete buildings, piers, bridge piers, overpasses against explosion and impact loads. Current protection technologies include exterior steel cladding, the addition of concrete walls, and sprayed polymer and metallic foam coating over the reinforced concrete structure. The addition of exterior steel cladding and concrete walls can be effective in increasing the resistance of structures to blast loads. However, they can increase the overhead placed on the existing structure and construction can be time consuming, costly and inconvenient for the occupants. Sprayed polymer can increase bending strength and effectively reduce spills, but requires spraying equipment and is very expensive (Wu et al, 2011).

With the development of the transportation industry, collision of ships with bridge piers, collision of cars at very high speed with bridge piers or pedestrian overpasses also frequently occur, resulting in significant economic losses (Zhou et al., 2020). Bridge damage from fast-vehicle collisions, a major problem in the transportation network, ranges from minor deterioration or spillage of fascia beams to almost complete bridge destruction. Repairing such damage is expensive and includes the costs of bridge repair and traffic rerouting, as well as indirect economic and social costs (Cheng et al., 2016). A reinforced concrete pier is an integral load-bearing component of the bridge structure, and its impact resistance is crucial to the overall safety of the concrete structure (Zhou et al., 2020).

1.2.Materials used by increasing the strength of the reinforced concrete structure

Concrete is one of the most economical building materials used in the construction of buildings in the construction industry. It is produced with a mixture of sand, gravel (aggregate), cement and water. If necessary, chemical and mineral additives can be added to this mixture mortar in appropriate mixing ratios. The most important reasons for preference are its easy and accessible production, its ability to be used without losing its strength for many years, and its low cost (Özgüden & Çağatay, 2020).

Although the aggregate and cement paste forming the concrete show elastic behavior, concrete is not an elastic material at high stress levels. As seen in Figure 1, while typical stress-strain curves of aggregate and cement paste are linear, the behavior of concrete under axial pressure is not linear. In other words, the properties of concrete as a composite material should not be considered as the sum of the properties of its components (Felekoğlu and Türkel, 2004).

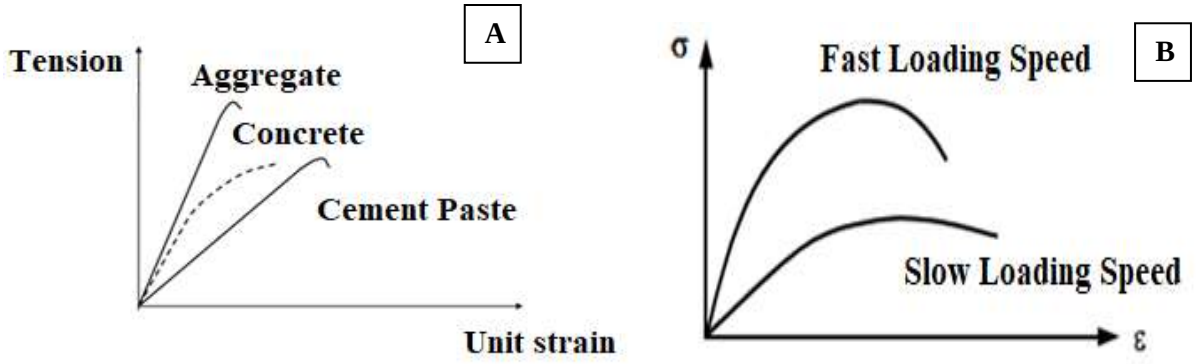


Figure 1. A)Typical tension-strain curves of concrete and concrete materials (Felekoğlu and Türkel, 2004)
B) Typical tension-strain curves of concrete at different loading speeds

Since concrete is a material that shows deformation depending on time, the loading rate is very important for the strength of the concrete. The strength value of the concrete decreases with the decrease of the loading speed. This is due to the time-dependent increase in deformations, namely the creep behavior. Figure 1-B shows the typical tension-strain relationship of concrete at different loading speeds.

The existing protection technologies in increasing the strength of concretes are generally made in the form of steel siding, adding concrete walls, spraying polymer and metallic foam on the coating. The addition of steel siding and concrete walls increases the durability of the building against impact load while increasing the dead load on the building. This causes the building to be built longer, more expensive and unusable. At the same time, the increase in the weight of the structure is a factor that negatively affects the earthquake resistance of the building. One of the alternative methods, polymer spraying on the structure increases the bending strength of the carrier elements and reduces debris. However, the required spraying equipment is quite expensive (Wu et al., 2011).

Fiber additives, one of the most important methods of increasing durability, have been used since ancient times. Among the fiber types, steel fibers are the most durable and used. However, carbon fibers are as economical and durable as steel fibers (Tabatabaei et al., 2013). In the new generation construction technology, the contribution of different materials and the effects of these materials by changing the additive methods are examined in order to increase the impact resistance of concrete (Yong, 2019).

1.3. Environmentally friendly materials used as additives to increase strength in reinforced concrete structures

Various additives are made to give flexibility to concrete and to increase its strength value. In the developing world, due to the increase in population and the decrease of natural resources day by day, the need to use all available resources more efficiently in the construction sector has arisen. At the same time, the use of waste materials in different sectors and for different purposes in order to minimize environmental pollution and to recycle waste efficiently is one of today's agenda. For this reason, efforts to realize different environmentally friendly additives in order to increase the strength of concrete in the construction sector have gained momentum (Tam et al., 2018).

Aluminum waste is one of the materials used to increase the strength of concrete samples within the scope of the project. In the literature, especially metal foams are one of the most evaluated products in this field. Metallic foam consists of a metal matrix (usually aluminum) impregnated with air pockets. In compression due to its long, plastic plateau, metallic foam allows for high energy absorption. The nearly constant stress level makes it an ideal material for reducing the effects of explosive charges on a structural system (Ashby et al. 2000; Montanini 2005). Newly developed portable and lightweight materials such as aluminum foam, sandwich panels, steel fiber additives are of great interest in increasing building durability against explosions and impacts due to their low dead load, being cheaper and having more energy absorption capacity than conventional technologies (Schenker et al., 2005). Newly developed mobile and light weight materials such as aluminum foams are very attractive for use as layers of protection in applications where the target is protection against terrorism, as they have lower loads, are cheaper and have higher energy absorption capacities than conventional technologies (Wu et al, 2011). Because of the excellent impact energy consumption of the closed cell aluminum foam and the strong corrosion resistance of the stainless steel reinforcement, it is of great importance to examine the protective performance of closed cell aluminum foam under impact load on concrete scaffolds after replacing the conventional. Equal strength stainless steel reinforced reinforcement, as this can provide a useful reference for the design of reinforced concrete structures in impact resistant design (Zhou et al., 2020).

One of the materials used to increase the strength of concrete samples within the scope of the project is glass waste. The back of the glass waste recycling, first started in Germany and Switzerland, but the recycling of glass waste in Turkey, ended the year of 1970. Glass is a 100% recyclable building material. Some of the millions of tons of waste glass that emerges every year in the world are used for recycling in glass production factories. Germany, which is one of the leading countries in waste glass recycling, can recycle 94% of waste glass and Sweden a great majority, such as 93%, while this rate in our country remained at the level of 66%. On the other hand, the methods used for the disposal of these waste glass are a serious cost and these costs are increasing day by day. For this reason, it has become important to investigate the usability of waste glasses in concrete and / or reinforced concrete structures. The fact that glass wastes can be used as strength-increasing products in concrete will reduce these disposal costs and have positive consequences for our country's economy (Özgüden & Çağatay, 2020).

In the literature, there are studies on the use of glass waste in the cement and concrete industry since the 1960s. The increase in these studies in recent years is particularly related to environmental regulations and waste disposal costs. The problem in the recycling of waste glass is that the glasses are dirty and have different colors, so extra processes are needed and these methods increase the cost. Therefore, new markets are needed for the recycling of mixed glass (Shi & Zheng, 2007).

The effect of the placement as well as the effect of the materials on the strength of the concrete is very important. The material to be added as an additive should be placed in a order to absorb the energy of the incoming impact and prevent damage to the concrete structure. Within the scope of the project, waste glasses were positioned at the center of the concrete material, and metal ring structures and discs of different sizes were placed in a honeycomb pattern. Sandwich structures are structures obtained by combining layers of materials with various properties between two metal plates according to the desired behavior. Honeycomb composite sandwich structures, on the other hand, are very light structures in which generally honeycomb-like hexagonal cellular honeycombs are placed between two metals (steel or aluminum), and are especially used in constructions requiring high mechanical strength where the energy generated as a result of impact is absorbed. The placement of honeycomb structure between the layers increases the moment of inertia and bending strength of the structure. Honeycomb composites are more expensive than other sandwich construction intermediate materials, and converting them into sandwich structures requires more special labor. It is generally used in the maritime, aviation and space industry to provide high mechanical strength (Petras, 1999).

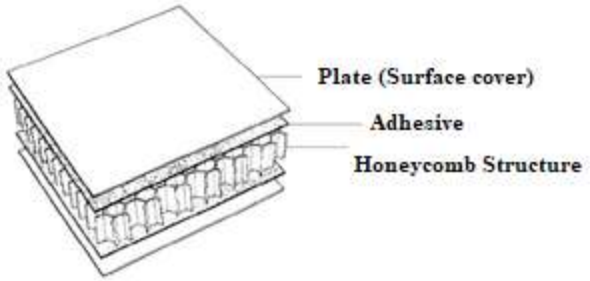


Figure 2. Honeycomb sandwich structure (Petras,1999)

Honeycomb is one of the two-dimensional cellular materials. It is an ideal cushion material due to its relatively low density and hardness, good and controllable deformation ability (Liu et al., 2008).

When the studies in the literature were examined, Su et al. Conducted large-scale physical model tests in their study in 2018 to examine the dynamic response of recycled broken glass in gabion baskets and its performance against successive rock impacts at energy levels up to 70 kJ. The cushioning performance of recycled broken glass has been compared to more traditional cushioning materials, including boulders and cellular glass clusters. The results reveal that recycled cracked glass can achieve a reduction of up to 144% and 128% respectively in transmitted wall loads and rock impact loads for the first impact, compared to cushion layers containing rock fragments. They can potentially reduce the recommended design load for a single rock impact in recycled broken glass-reinforced structures by up to three times. Also, the charge diffusion angle of recycled cracked glass is three times greater than cellular glass aggregates. The trend observed in diffusion angle showed that the

transmitted charge for recycled cracked glass is more homogeneously distributed across the barrier wall compared to cellular glass aggregates (Su et al., 2018).

In the study conducted by Wu et al. In 2011, quacistatic tests were performed on two types of aluminum foam samples and primary parameters for the mechanical properties of aluminum foam samples were obtained. Later, these two types of aluminum foam were used to protect the reinforced concrete plates, and a series of tests were conducted to investigate the performance of aluminum foam shielded boards against bursting loads, and it was observed that aluminum foam increased resistance to bursting loads (Wu et al., 2011).

In their study in 2018, Ng et al., The advent of using lightweight cellular glass as an alternative cushion layer, as gabions, the most widely used cushion layer to protect hard debris-resistant barriers against rock impact, contain heavy rock fragments that cannot be easily transported into steep natural terrain, Provided an innovative approach to absorb. In this work, cellular glass was subjected to successive impacts to replicate the dynamic loading of rocks using a large-scale pendulum assembly. The results reveal that for a single impact at 70 kJ, the break exhibited by cellular glass resulted in 25% lower impact force compared to gabions that rely heavily on rearrangement of rock fragments to absorb energy. However, gabions exhibited more effective charge dissipation with a diffusion angle three times greater than cellular glass (Ng et al., 2018).

Liu et al. Conducted some experiments in their study in 2008 to examine the semi-static and dynamic cushion properties of three types of aluminum honeycomb and four types of aluminum foam in order to find the appropriate cushion material that can absorb the impact of spacecraft during the landing phase. After analyzing the stress / energy-strain curves and cushioning properties from the experiments, four types of characterization methods have been revealed on the cushion materials. These methods can comprehensively evaluate the cushion properties and can be used to guide the design of the shock absorber. After analyzing and summarizing the cushioning properties of the tested aluminum honeycomb and aluminum foam by these methods, it has been proven that coarse-perforated aluminum foam with a nominal crush strength of 0.140.15MPa has optimum buffer properties in all seven types of samples (Liu et al., 2008).

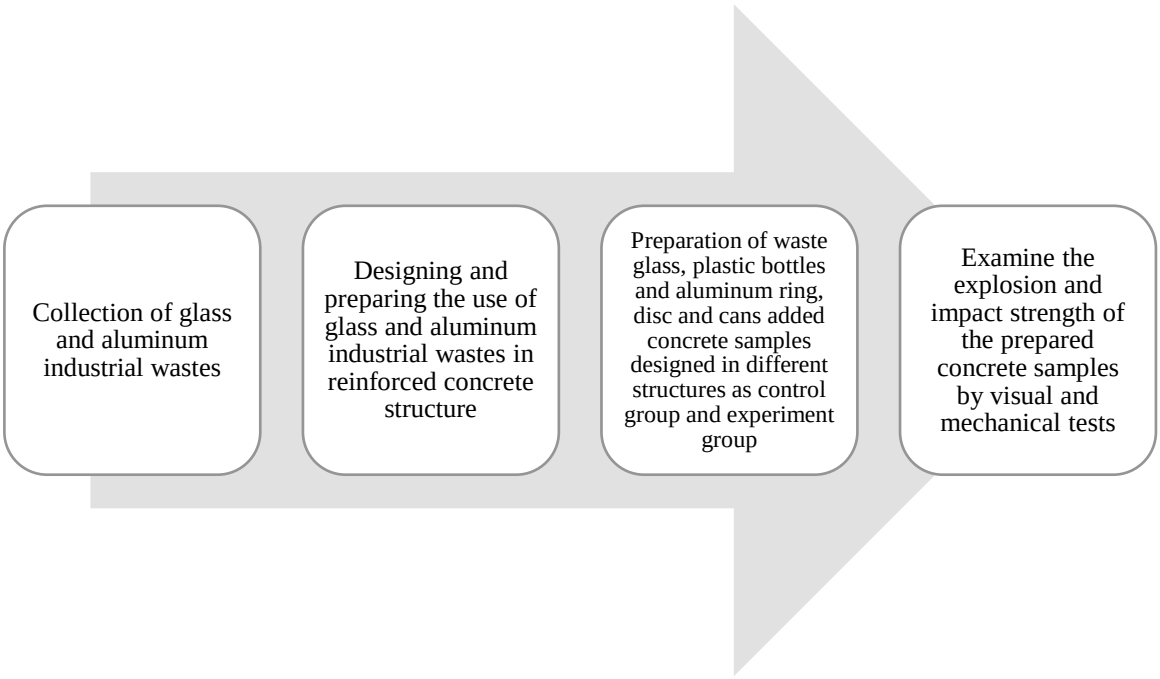
In the study carried out by Palanivelu et al. in 2011, it was proposed to cover recyclable waste products such as metal beverage boxes to protect concrete sewer pipes from an explosive load, and air spray experiments were carried out. The use of empty beverage boxes reduced the peak load transferred to the structure and significantly extended the breaking time (Palanivelu et al., 2011). Within the scope of the project, beverage boxes and plastic bottles were added to the concrete materials in a honeycomb pattern, and their resistance to impact was examined. No similar literature has been found on the admixture of plastic materials to concrete materials.

2. Material and Method

2.1. Materials and Devices

Materials used within the scope of the project and devices used during experimental studies: waste glass bottles, waste plastic bottles, waste aluminum beverage boxes and industrial aluminum waste, cement, water, reinforcement, aggregate (maximum grain size: 4.75 mm), steel fiber (length: 60mm, diameter: 75 mm), impact loading test setup, pressure test device (Dinç Machine, D201.A, Capacity 2000kN) weight (200 kg) used in impact load test, concrete mixer (volume 100 lt), electronic balance, shovel, hand truck, iron cutting machine, vise, glass shredding machine, concrete molds, meter, wrench, ratchet, crowbar, gantry crane, steel rope, silicon, strong band, trowel, mold oil, pallet truck, drill, hilti, cuts, styrofoam foam.

2.2. Experimental Flow-Chart



2.3. Collection and Preparation of Waste Glass, Plastic Bottles, Aluminum Beverage Boxes and Industrial Aluminum Parts

Within the scope of the project, waste glass and plastic bottles and aluminum beverage boxes used to strengthen concrete structures were collected from cafes, restaurants and waste bins. The collected glass bottles were crushed in homogeneous sizes using small metal balls in the glass breaking device and made to be used as an additive to concrete structures.



Figure 3. Preparation of waste glass samples

Aluminum waste obtained from industrial organizations was prepared as ring structures (2 different thicknesses) and disc structures obtained from aluminum clippings and made to be used for contribution to concrete structures.



Figure 4. Preparation of aluminum ring samples (0.5 and 1 mm thick and 75 mm in diameter)



Figure 5. Preparation of disc samples from scrap aluminum waste



Figure 6. Preparation of waste plastic bottle samples



Figure 7. Preparation of waste aluminum beverage can samples

2.4. Preparation of Concrete Molds

For the molds in which concrete samples will be prepared, 5-6 mm thick wooden plates were assembled and turned into 50 × 50 cm squares. Mold joints are sealed with silicone to prevent liquid leakage. Before each concrete sample was poured, the molds were oiled to prevent the mortar from sticking. 2.5 cm thick pieces were cut from the styrofoam foam and placed in the mold, and square reinforcements were placed on top. The ready-made reinforcement parts were bent with a vice and turned into a handle for the stage of removing the concrete and placed in the mold in a way that it would stand perpendicular to the mold.



Figure 8. Preparation of concrete molds

2.5. Preparation of Control Group Concrete Samples

In order to prepare the waste glass-added concrete samples, firstly, 43.8 kg of aggregate, 20.25 kg of cement and 9.8 kg of water were weighed and mixed in a concrete mixer. The prepared concrete mixture was poured into the mold to be 5 cm and leveled with a trowel. It was covered and left to dry for 1 week. 65.7 kg of aggregate, 30.375 kg of cement, 14.7 kg of water, 3 kg of steel fiber (length: 60 mm, diameter: 75 mm) were weighed and mixed in the concrete mixer. The concrete mixture obtained was poured into molds as the upper concrete layer, smoothed with a trowel and left to dry for 1 week. At the end of the period, the prepared concretes were removed from the mold with the help of a crane. 2 of each concrete were prepared as a control group.

2.6. Preparation of Waste Additive Concrete Samples

Various waste material additives made to increase concrete strength were placed in the following designs and prepared for strength tests.

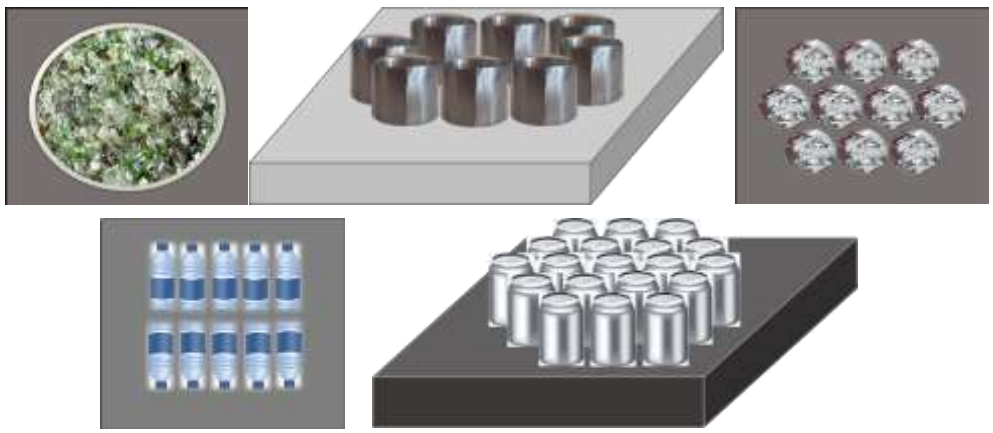


Figure 9. Placement designs of waste glass plastic bottles, aluminum beverage boxes, aluminum rings and discs on concrete

2.6.1. Preparation of Waste Glass Additive Concrete Samples

In order to prepare the waste glass-added concrete samples, firstly, 43.8 kg of aggregate, 20.25 kg of cement and 9.8 kg of water were weighed and mixed in a concrete mixer. The prepared concrete mixture was poured in the mold to be 5 cm and leveled with a trowel. It was covered and left to dry for 1 week. The ring prepared from aluminum plate with a height of 7 cm and a diameter of 25 cm was placed on the concrete and broken glass pieces were poured until the height was filled. The top of the ring containing the prepared glass pieces was wrapped with a bag and closed. 65.7 kg of aggregate, 30.375 kg of cement, 14.7 kg of water, 3 kg of steel fiber (length: 60mm, diameter: 75 mm) were weighed and mixed in the concrete mixer. The concrete mixture obtained was poured into molds containing waste glass pieces prepared as the upper concrete layer, smoothed with a trowel and left to dry for 1 week. At the end of the period, the prepared concretes were removed from the mold with the help of a crane. Two concrete samples were prepared from each concrete as an experimental group.



Figure 10. Preparation of waste glass-reinforced concrete samples

2.6.2. Preparation of Waste Aluminum Rings Additive Concrete Samples

For the preparation of waste aluminum-added concrete samples, firstly, 43.8 kg of aggregate, 20.25 kg of cement and 9.8 kg of water were weighed and mixed in a concrete mixer in the lower concrete layer. The prepared concrete mixture was poured in the mold to be 5 cm and leveled with a trowel. Ring structures (0.5 and 1 mm thick and 75 mm in diameter) formed with aluminum waste were dipped lightly in concrete and arranged in a honeycomb shape. It was covered and left to dry for 1 week. The part containing the prepared aluminum rings was wrapped with a bag and closed. 65.7 kg of aggregate, 30.375 kg of cement, 14.7 kg of water, 3 kg of steel fiber (length: 60mm, diameter: 75 mm) were weighed and mixed in the concrete mixer. The concrete mixture obtained was poured into molds containing aluminum rings prepared as the upper concrete layer, smoothed with a trowel and left to dry for 1 week. At the end of the period, the prepared concretes were removed from the mold with the help of a crane. Concretes containing 0.5 mm and 1 mm aluminum rings were prepared separately and 2 from each as an experimental group.



Figure11. Preparation of concrete samples with additives of waste aluminum rings (0.5 and 1 mm thick and 75 mm in diameter)

2.6.3. Preparation of Waste Aluminum Disc Additive Concrete Samples

For the preparation of waste aluminum disc-added concrete samples, firstly, 43.8 kg of aggregate, 20.25 kg of cement and 9.8 kg of water were weighed and mixed in a concrete mixer in the lower concrete layer. The prepared concrete mixture was poured in the mold to be 5 cm and leveled with a trowel. The disc structures created with aluminum wastes were dipped lightly in the concrete and arranged in a way that they were collected in the center of the concrete. It was covered and left to dry for 1 week. The part containing the prepared aluminum discs was wrapped with a bag and closed. 65.7 kg of aggregate, 30.375 kg of cement, 14.7 kg of water, 3 kg of steel fiber (length: 60mm, diameter: 75 mm) were weighed and mixed in the concrete mixer. The concrete mixture obtained was poured into molds containing aluminum discs prepared as the upper concrete layer, and the top was smoothed with a trowel and left to dry for 1 week. At the end of the period, the prepared concretes were removed from the mold with the help of a crane. Two concrete samples were prepared from each concrete as an experimental group.



Figure 12. Preparation of waste aluminum disc-reinforced concrete samples

2.6.4. Preparation of Waste Plastic Bottle Additive Concrete Samples

In order to prepare the waste plastic bottle additive concrete samples, firstly, the lower concrete layer was weighed 43.8 kg of aggregate, 20.25 kg of cement and 9.8 kg of water and mixed in a concrete mixer. The prepared concrete mixture was poured into the mold to be 5 cm and leveled with a trowel. The caps of the waste plastic bottles were fixed to the bottle with adhesive, and the bottles were arranged horizontally in the form of a honeycomb by pressing lightly on the concrete in an air-filled, cushion-like structure. It was covered and left to dry for 1 week. 65.7 kg of aggregate, 30.375 kg of cement, 14.7 kg of water, 3 kg of steel fiber (length: 60mm, diameter: 75 mm) were weighed and mixed in the concrete mixer. The

resulting concrete mixture was poured into molds containing waste plastic bottles prepared as the upper concrete layer, smoothed with a trowel and left to dry for 1 week. At the end of the period, the prepared concrete was removed from the mold with the help of a crane. Two pieces of each concrete were prepared as the experimental group.



Figure 13. Preparation of waste plastic bottle added concrete samples

2.6.5. Preparation of Waste Aluminum Beverage Can Additive Concrete Samples

For the preparation of waste aluminum beverage can additive concrete samples, firstly, the lower concrete layer was weighed 43.8 kg of aggregate, 20.25 kg of cement and 9.8 kg of water and mixed in a concrete mixer. The prepared concrete mixture was poured into the mold to be 5 cm and leveled with a trowel. Waste aluminum beverage boxes were arranged vertically in a honeycomb shape by pressing lightly on the concrete so that their open parts were embedded in the concrete. It was covered and left to dry for 1 week. 65.7 kg of aggregate, 30.375 kg of cement, 14.7 kg of water, 3 kg of steel fiber (length: 60mm, diameter: 75 mm) were weighed and mixed in the concrete mixer. The resulting concrete mixture was poured into molds containing waste aluminum beverage boxes prepared as the upper concrete layer, smoothed with a trowel and left to dry for 1 week. At the end of the period, the prepared concrete was removed from the mold with the help of a crane. Two pieces of each concrete were prepared as the experimental group.



Figure 14. Preparation of waste aluminum beverage can additive concrete samples

2.7. Preparation and Pressure Test of Concrete Samples Containing Steel Fiber

The samples, which were taken into cube molds from the upper concrete layer prepared in each test stage and dried for 1 week, were kept in the curing water pool for 28 days. The cube-shaped concretes taken at the end of the period were tested in the pressure test device.



Figure 15. Preparation and testing of concrete samples containing steel fiber

2.8. Preparation of Impact Test Setup of Waste Glass and Aluminum Additive Concrete Samples and Performing Tests

In the mechanism prepared for impact tests of concrete samples produced in duplicate by making waste glass and different types of aluminum additives, 200 kg weight was left on the concretes with free fall from 1m and 2m heights. As a result of the weight falling on the concrete, the amount of height on the surface was measured with an electronic caliper, visual analysis was made to determine the amount of damage in the concrete, and the behavior of the concrete against impact was measured by measuring the load-time and graphing it.



Figure 16. Preparation of impact test mechanism of waste glass and aluminum additive concrete samples and performing tests

3. Results

3.1. Compressive Strength Test of Concrete Samples Containing Steel Fiber

According to the results obtained in the pressure test, 27 N/mm^2 of the concrete samples prepared for the glass admixture, 46.39 N/mm^2 of the concrete samples prepared for the 0.5mm thick aluminum ring admixture, 42.95 N/mm^2 of the concrete samples prepared for the 1 mm thick aluminum ring admixture, for the aluminum disc admixture. It is seen that the concrete samples prepared with 50.47 N/mm^2 plastic bottle additives show resistance up to 52.23 N/mm^2 and the concrete samples with aluminum beverage can additives up to 49.78 N/mm^2 pressure.

Table 1. Pressure Test of Concrete Specimens Containing Steel Fiber

Concrete Sample	Pressure Test Result (N/mm^2)
Control Concrete Sample	
Waste Glass Additive Concrete Sample	27
Waste Aluminum Additive (0.5 mm thickness) Concrete Sample	46.39
Waste Aluminum Additive (1 mm thickness) Concrete Sample	42.95
Waste Aluminum Disc Concrete Sample	50.47
Waste Plastic Bottle Additive Concrete	52.23
Waste Aluminum Beverage Box Reinforced Concrete	49.78

3.2. Impact Tests of Waste Glass and Aluminum Additive Concrete Samples

3.2.1. The amount of change in surface height after impact

Height measurements were taken from 3 different points (middle and 2 different corners) from the surface of the concrete samples before the impact test. After the impact test, height measurements were made at the same points and the amount of change in the surface height was determined.

Table 2. The amount of change in surface height after impact

Concrete Sample	Height Before Impact Test (mm)						Height After Impact Test (mm)						Amount of Height Change in Surface Height (mm)					
	2 m			1 m			2 m			1 m			2 m			1 m		
	1. corner	middle	2. corner	1. corner	middle	2. corner	1. corner	middle	2. corner	1. corner	middle	2. corner	1. corner	middle	2. corner	1. corner	middle	2. corner
Waste Glass Additive Concrete Sample	93.9	125	92.3	92.6	129	93.5	92.1	88	92.9	91	93	95	1.8	37	0.6	1.6	36	1.5
Waste Aluminum Additive (0.5 mm thickness) Concrete Sample	101	116	100	94.6	121	95.8	93.5	94	95	94.5	99	95.5	7.5	22	5	0.14	22	0.28
Waste Aluminum Additive (1 mm thickness) Concrete Sample	94	137	94.2	94	108	98	95.4	97	96.1	93	92	94	1.4	40	1.9	1	16	4
Waste Aluminum Disc Concrete Sample	94.6	96.5	96	92.5	94	93.3	94.08	144	95.01	95	112	102	0.53	47	0.95	2.5	18	9
Waste Plastic Bottle Additive Concrete	94	98	96	94	97	105	95	124	96	98	121	108	1	26	0	4	24	3
Waste Aluminum Beverage Box Reinforced Concrete	95	97	97	96	96	98	100	148	99	96	140	101	5	51	2	0	44	3

When the data in the table is examined, the low change in the surface height after impact in all samples shows that the additives increase the impact strength of the concrete.

3.2.2. Impact test visual analysis

Visual analysis of waste glass and aluminum-added concrete was performed before and after the impact test.



Figure 17. Visual analysis of control group non-additive concrete



Figure 18. Visual analysis of waste glass-reinforced concrete



Figure 19. Visual analysis of concrete with waste aluminum ring (0.5 mm thickness)

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Figure 20. Visual analysis of concrete with waste aluminum ring (1 mm thickness)



Figure 21. Visual analysis of waste aluminum disc reinforced concrete



Figure 22. Visual analysis of waste plastic bottle reinforced concrete



Figure 23. Visual analysis of waste aluminum beverage box reinforced concrete

In the visual analysis of the concretes before and after the impact test application, it is seen that the concrete without additives, which is the control group, crumbled, and the layers formed with waste glass, plastic bottles, aluminum beverage boxes and aluminum rings of different thicknesses increased the strength by showing a barrier effect when the impact was applied to the concrete. The integrity of the concrete is intact and there is a damage limited to the affected area. When compared with the post-impact condition of the control group, it is seen that the damage level is considerably reduced. When the concretes containing different additives are compared, it can be said that the concretes with the addition of waste glass are more durable than the concretes with the addition of aluminum rings, discs, boxes and plastic bottles.

3.2.3. Impact Test Results

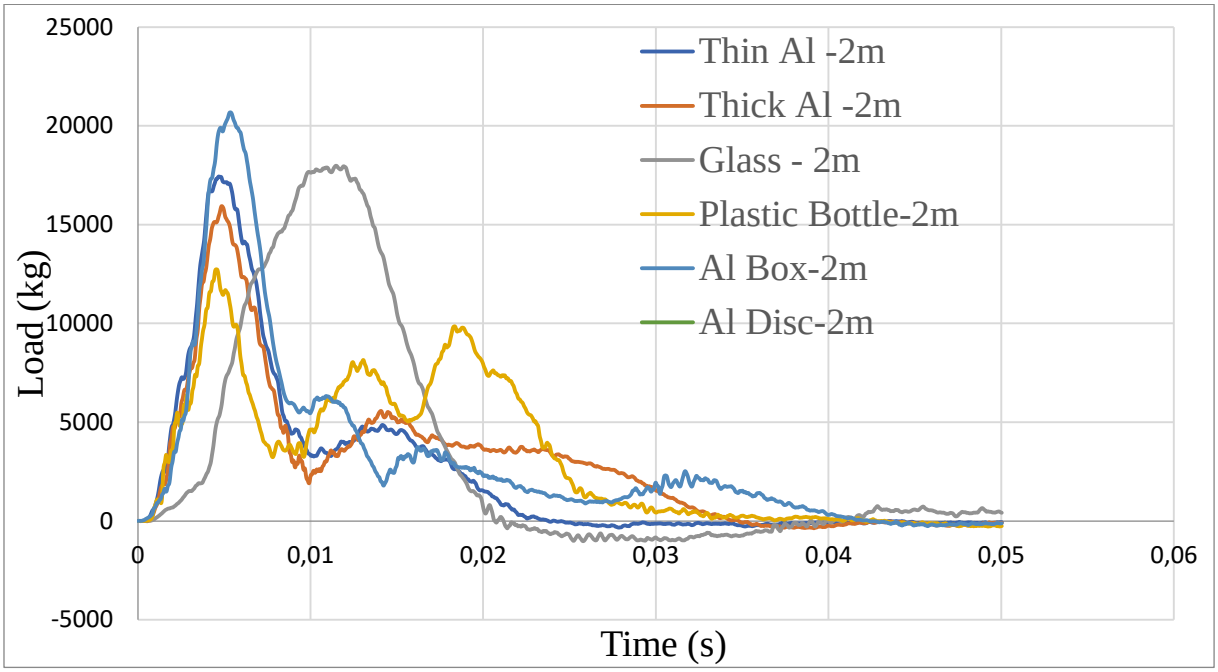


Figure 24. 2 m Free Fall Impact Test Response-Time Change

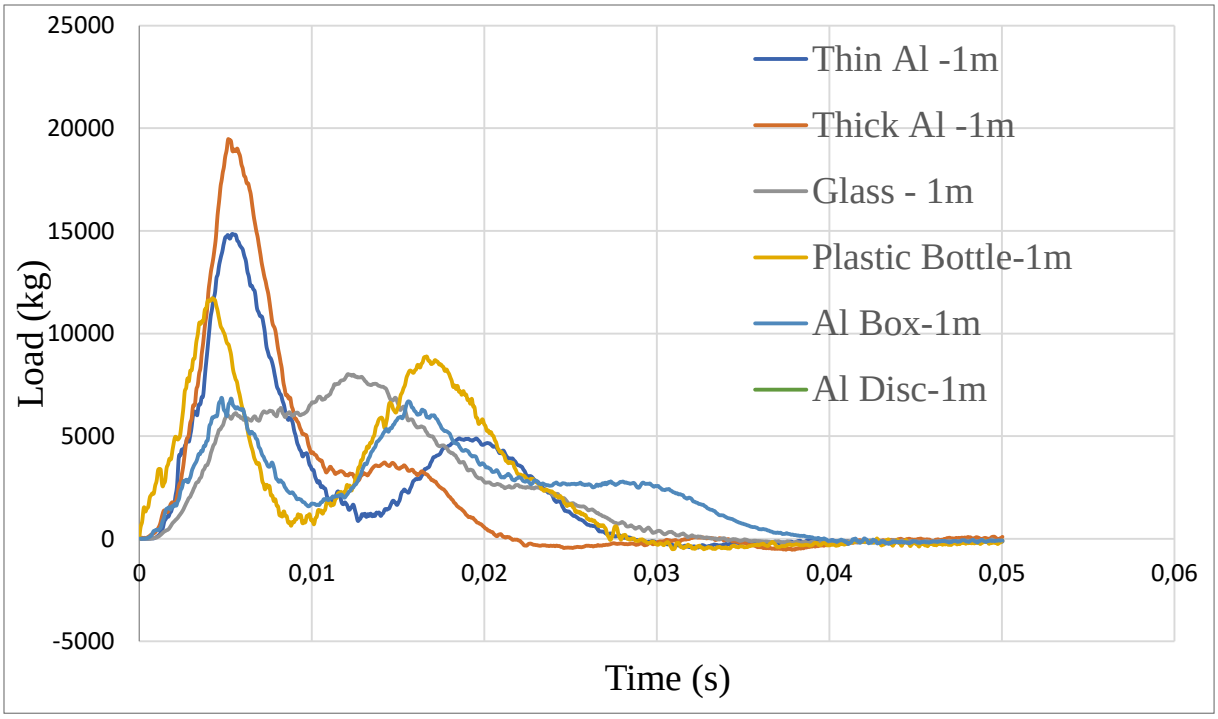


Figure 25. 1 m Free Fall Impact Test Response-Time Change

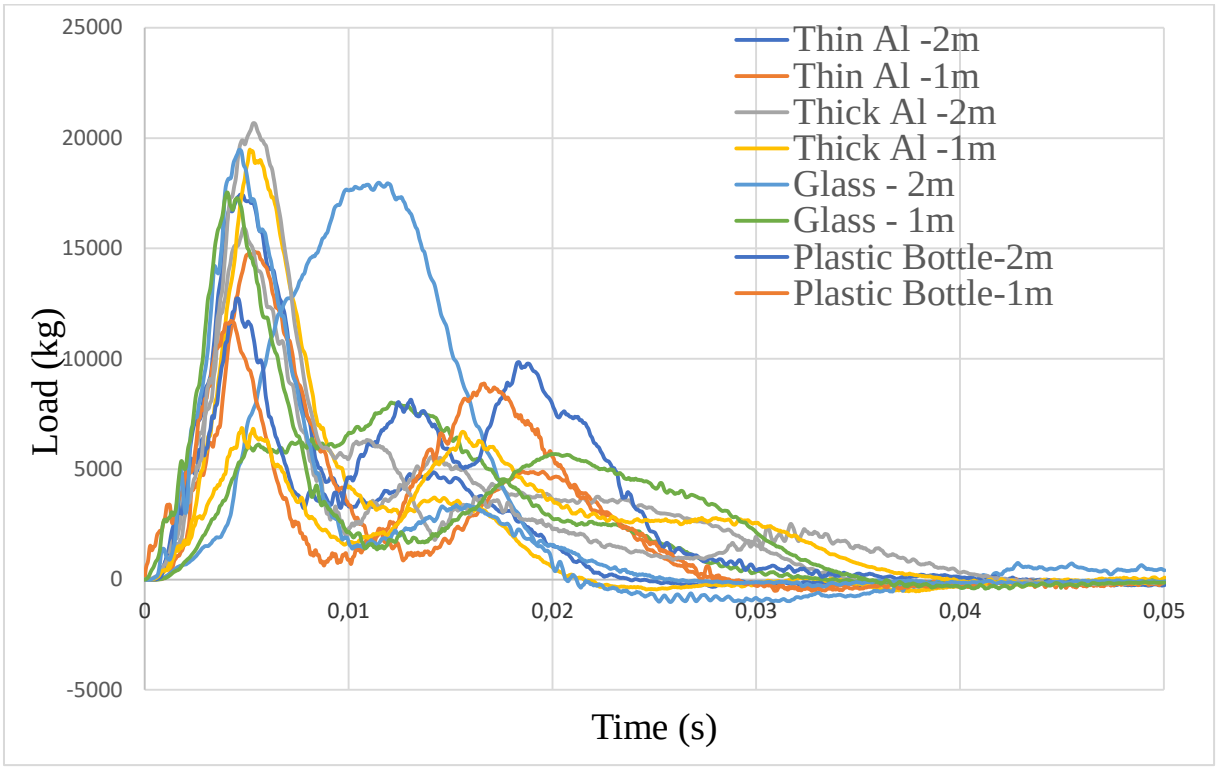


Figure 26. All Impact Test Results

Figure 24 and Figure 25 present the time variation of the reaction force measured from the supports during a 2 m and 1 m free fall impact, respectively. When the impact results applied from a height of 2 m are examined in Figure 24, it is seen that the maximum reaction force is measured in all concretes. For this height, when the concrete with two aluminum rings was examined, higher reaction force was measured in the concrete with thin aluminum rings. Concretes with aluminum disc additives with fine aluminum additives at 2m free fall impact; It showed similar behavior with thick aluminum reinforced concrete at 1 m free fall impact.

This shows that thin rings are less crushed at this height and have less cushioning effect. As seen in Table 2, the slump is 22 mm in thin aluminum added concrete, 40 mm in thick aluminum added concrete, and 47 mm in aluminum disc added concrete. Thicker aluminum rings, which were crushed more, transferred less force to the support.

On the other hand, the cushioning effect is more in glass-reinforced concrete. In this concrete, the force increased more slowly and remained constant for a short time at the maximum value.

This shows that the glass additive absorbs more energy by crushing and crumbling. The excess amount of collapse measured at 37 mm also confirms this.

When the 2 m free fall impact test results of the concrete samples with aluminum beverage cans were examined, it was observed that the aluminum boxes placed at the edges of the midpoint where the impact was applied were also crushed, thus absorbing the incoming impact energy with the contribution of all boxes.

When the concrete samples with plastic bottle additives were examined, it was observed that these bottles were completely destroyed. For these two concrete tests, when the slump was examined, it was measured that the concrete with plastic bottle additives collapsed by 26 mm, and the concrete with aluminum can additives by 51 mm. Although plastic bottles were completely crushed and shattered, they dampened the impact load more than aluminum boxes during this time and provided lower forces to be transferred to the supports as seen in Figure 24. This situation can be explained by the fact that the plastic bottles with their mouths are crushed by the impact of the impact, bursting and absorbing the impact force with the cushion effect. However, since the air is not completely trapped in the aluminum boxes, they were more crushed and could not show the same cushioning effect and transferred more force to the supports. On the other hand, the plastic bottles could not stop the impact and could not prevent the concrete below from breaking down, as their strength was completely exhausted after they burst. However, since the aluminum boxes absorb energy while being crushed, they were able to relatively protect the concrete below.

When Figure 25 is examined for the lower speed impact applied from a height of 1 m, it is seen that the thin aluminum ring concrete has a more cushioning effect and transfers less force, unlike the high speed impact in concretes with aluminum rings. While this concrete collapsed by 22 mm, the concrete with thick aluminum rings collapsed by 16 mm, and the concrete with aluminum disc additives collapsed by 18 mm. Thick ring concrete was crushed less and transferred the impact force more.

On the other hand, it is seen that the glass-reinforced concrete absorbs the force to a large extent and transmits a much lower force acting over a longer period of time. Glass-reinforced concrete was crushed by 36 mm and showed more crushing than the others. The glass pieces were crushed and absorbed the energy and acted as a cushion by significantly restricting the transfer of the sudden impact force to the supports.

When the results of the 1 m free fall impact test are examined, it is seen that the aluminum boxes with additives in the concrete samples with aluminum boxes are partially crushed in the center where the impact is applied, but they are not completely shattered. In addition, it was also investigated that these aluminum boxes, which remained intact, did not transfer the energy to the lower parts of the concrete by acting as a cushion against the applied impact energy and that the concrete remained intact.

It is seen that the concrete samples with plastic bottle additives were damaged very little in the impact test performed at this height, there was no breakage and the plastic bottle additives

inside were also intact. Although the impact applied from this height deformed the plastic bottles and dented them 24 mm, it could not burst. However, the fact that the plastic bottles did not burst caused a higher impact force to be transferred to the supports compared to the crushed aluminum boxes. More crushed aluminum boxes absorbed more energy while being crushed.

The results obtained from the impacts made from both heights are given in Figure 26 collectively. As can be seen from this graph, glass-reinforced concrete has the best cushioning properties for both heights. The glass additive was crushed more and dampened the force more. After the glass reinforced concrete, the thin aluminum ring concrete comes. Although this concrete transmits slightly more force for high velocity impact than thick one, it has more damping than thick aluminum at low velocity impact. This can be explained by the fact that thin aluminum rings can be crushed more. It is seen that concretes with plastic bottle additives are more resistant to impact from 1 m height at low speeds, and that their resistance to impact from 2 m height is lower. For concretes with plastic bottle additives, it is seen that the resistance of plastic bottles not bursting in the impact from 1 m height increases significantly, but after this critical impact force is exceeded and plastic bottles explode in the concrete, the protection effect against strength decreases slightly in the impact made from a height of 2 m. However, it has also been determined that the resistance of concrete with aluminum can additives is high against impact from a height of 2 m.

The energy absorbed by the materials in the concrete during impact can be calculated approximately. The elastic energy absorbed by an elastic material during displacement can be taken as the area under the force-displacement graph (Figure 27). When the force disappears, that is, when it drops to zero, if the displacement of the material also returns to zero, all of this absorbed energy is returned to the system, if the displacement never returns and the □max displacement it undergoes remains the same, all of this energy is absorbed. Impact force and displacement could not be measured simultaneously in the experiments. However, the values of the displacement, that is, the amount of collapse, and the maximum force reached are known. Assuming that the measured collapse amount is equal to □max and the maximum measured force is equal to Fmax, and these two values are realized at the same time, that is, the maximum value of the collapse is reached when the force is maximum, the energy absorbed by the concrete during the impact can be calculated.

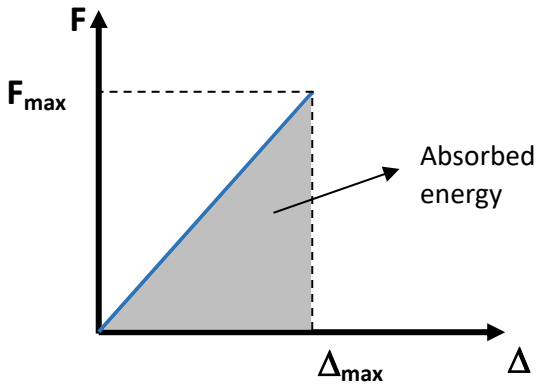


Figure 27. Energy stored in elastic material

With these assumptions, the following calculations have been made in order to determine the damping amounts after impact tests and the results are summarized in Table 3 and Figure 28.

1. The collapse amounts (Δx_{max}) of the tested concrete samples before and after the impact test were taken with calipers and converted into meters in units.
2. The peak Fmax values in kg unit obtained from the load-time graphs of each concrete sample were multiplied by 9.81 m/s^2 and converted to Newton unit.
3. Potential energy = mgh and kinetic energy $= \frac{1}{2}$ mV^2 from these formulas, assuming that all existing potential energy is transformed into kinetic energy, Impact energy was calculated by deducting this $V = \sqrt{2gh}$ formula.
4. A comparison was made with the obtained data by calculating Impact energy, Absorbed Energy and Absorption Percentage using the following equations.

Absorbed energy $E_S = \frac{F_{max} \text{x } \Delta x_{max}}{2}$

Impact energy $E_{initial} = \frac{1}{2} mV^2$

$$\% \, Absorbed \; Energy = \frac{Absorbed \; Energy}{Impact \; Energy} \; x \; 100$$

Table 3. Calculations of impact tests of concrete samples

Concrete Sample	Mass of Impact (kg)	Impact Speed (m/s)	F_{max}(N)	Δx_{max}(m)	Impact Energy (J)	Absorbed Energy (J)	Absorption Percentage %
Glass Additive (1 m high.)	200	4.4	78656.58	0.036	1962	1415.8	72.2
Glass Additive (2 m high.)	200	6.3	176364.18	0.037	3924	3262.7	83.1
Aluminum Ring Additive (0.5mm) (1m high.)	200	4.4	145698.12	0.022	1962	1602.7	81.6
Aluminum Ring Additive (0.5mm) (2m high.)	200	6.3	171027.54	0.022	3924	1881.3	47.9
Aluminum Ring Additive (1mm) (1m high.)	200	4.4	191039.94	0.016	1962	1528.3	77.9
Aluminum Ring Additive (1 mm) (2m high)	200	6.3	156302.73	0.040	3924	3126	79.7
Aluminum Disc Additive (1m high)	200	4.4	191010.51	0.018	1962	1719.1	87.6
Aluminum Disc Additive (2m height)	200	6.3	172047.78	0.047	3924	4043.1	*
Plastic Bottle Additive Concrete (1m)	200	4.4	114996.05	0.024	1962	1380	70.3
Plastic Bottle Additive Concrete (2m)	200	6.3	124949.18	0.026	3924	1624	41.4
Aluminum Beverage Box Additive Concrete (1m)	200	4.4	67335.34	0.044	1962	1481.45	75.5
Aluminum Beverage Box Additive Concrete (2m)	200	6.3	202870.5	0.051	3924	5173	*

Note: Since the sample marked with * is crushed too much, the max. strongly max. It is thought that the assumption that the crushing occurs at the same time is not valid, so the absorbed energy is more than the impact energy.

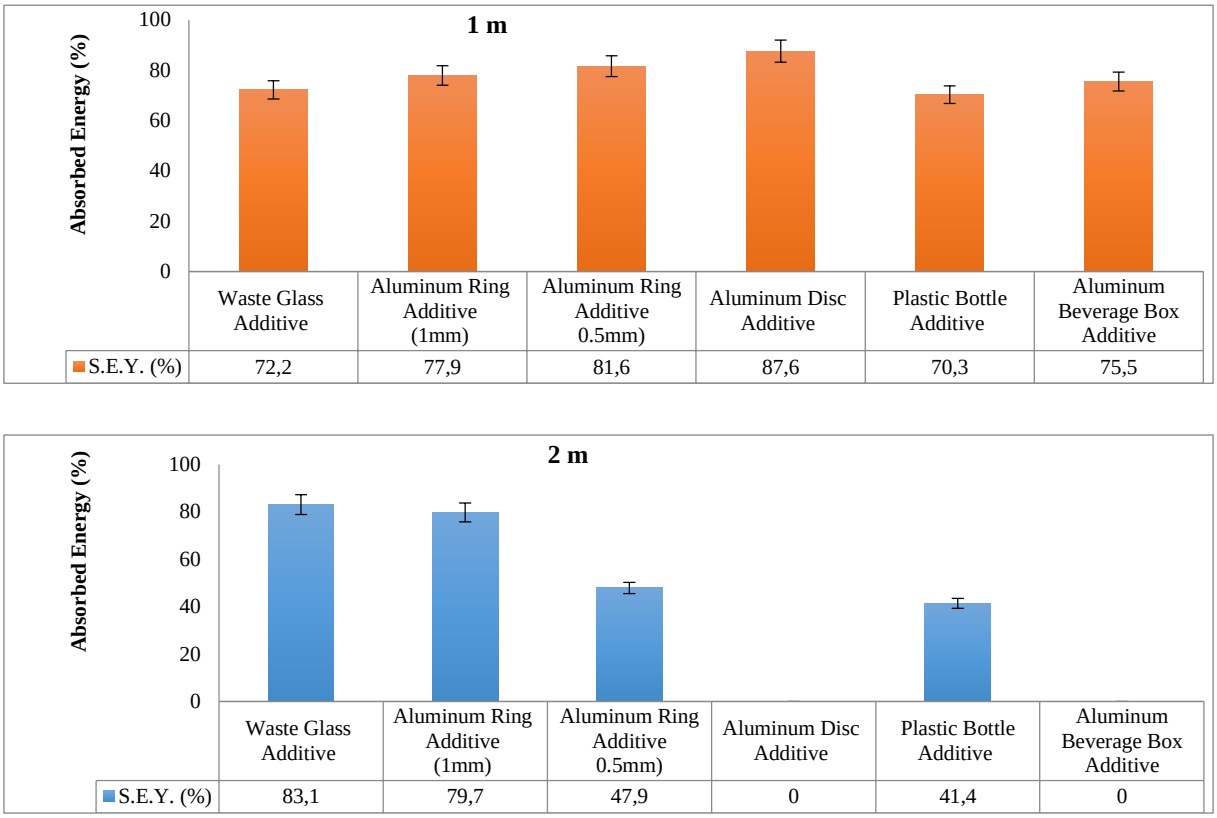


Figure 28. Comparison of absorbed energy percentages

It is seen that the absorbed energy values in the table and the results obtained are compatible with the results obtained when the load-time change is examined. In the impact test made from a height of 1 m, the amount of energy absorbed is very close to each other, and the concrete with aluminum disc additive absorbs the energy by the highest percentage. The crushing amount of the aluminum disc added concrete and the visual condition of the sample also support that this sample shows the best performance for this height. However, the load transferred by this concrete to the supports is still at the same level as the others. In the impact test made from a height of 2 m, the concrete with aluminum disc additive was crushed too much and lost its cushioning feature for this energy level. For this energy level, the aluminum disc added concrete absorbed the most energy with approximately 87.6%, while the glass-added concrete absorbed 83.1%. Glass-added samples are the concrete that transfers the least load to the supports. However, glass reinforced concrete showed the best performance according to both criteria. Glass reinforced concrete is followed by thick aluminum ring concrete. It is seen that the concrete with aluminum disc additive performs well at low impact energy levels, but cannot act as a cushion for high energy levels. It is observed that concrete samples containing waste plastic and aluminum beverage boxes absorb more than 70% of the impact, especially from a height of 1 m.

4. Conclusion and Discussion

Within the scope of the project, waste glass, plastic bottles and plastic bottles that can be used in the columns, which are the most important part of the strength of the buildings, are aimed at preventing the damages that may occur as a result of impacts and explosions in reinforced concrete structures, the damages that may occur on the bridge piers after a vehicle accident on the highways, and the impact-based damages that may occur after the ship collision on the piers. Industrial aluminum reinforced concrete materials in different forms were produced and their strengths were analyzed by visual and mechanical tests. Glass, plastic bottles and waste aluminum rings with different thicknesses in honeycomb pattern, discs and beverage boxes, which are important industrial waste materials today, were used in the developed concrete materials. These additives acted as a cushion/barrier as a result of the impact on the concrete, absorbing the energy resulting from the impact or explosion in this way, and protecting the concrete from major damages. In addition, the use of these products, which are waste materials in the industrial sense, in the construction sector contributed to the further transformation and the economy. When the visual and mechanical test results of the concrete samples developed to be used in the columns of the buildings to be strengthened in the project are compared;

- In the results obtained in the pressure test, it is seen that the prepared steel fiber reinforced concrete samples show resistance up to 52.23 N/mm2 pressure.
- Compared to the control groups without additives in all samples, the low change in surface height after impact indicates that the additives increased the impact strength of the concrete.
- In the visual analysis of the concrete before and after the impact test application, it is seen that the layers formed with waste glass and aluminum rings, discs, beverage boxes and plastic bottles of different thicknesses increase the strength by showing a barrier effect when impact is applied to the concrete. The integrity of the concrete is intact and there is a damage limited to the affected area. When compared with the post-impact condition of the control group, it is seen that the damage level is considerably reduced. When the concretes containing different additives are compared between them, it is seen that the concretes with aluminum disc additives absorb approximately 87.6% of energy.
- When the load-time graph of the impact test results is examined, it is seen that the waste glass-added concrete exhibits more ideal behavior for both heights tested and has the best cushioning feature. The glass additive was crushed more and dampened the force more. By transmitting force at a lower level but for a longer period of time, it ensures that the underlying concrete is less damaged and the impact is better absorbed. After the glass reinforced concrete, the thin aluminum ring concrete comes. Although this concrete transmits slightly more force for high velocity impact than for thick one, it has more damping than thick aluminum and aluminum disc at low velocity impact. This can be explained by the fact that thin aluminum rings can be crushed more. It is seen that concretes with plastic bottle additives are more resistant to impact from 1 m height at low speeds, and that their resistance to impact from 2 m height is lower. It has also been determined that the strength of concrete with aluminum can additives is high against impacts from a height of 2 m. It can be said that aluminum boxes and plastic bottles also absorb a good level of impact for impacts applied from a height of 1 m.

Addition of concrete walls, steel exterior cladding or various additives used in the construction industry to increase strength cannot provide sufficient strength increase, and increase the production time and cost of the building. When the results obtained are evaluated, it is seen that the developed concrete samples can be an economical concrete alternative that can be used in the column parts of the buildings, which will increase the strength significantly, and which can be easily found and produced. The fact that the use of waste glass, plastic and aluminum plates in concrete strength as developed in the project is not encountered when literature research is carried out in the field of the project shows the originality of the project. Damages to buildings as a result of explosions, impacts and blows caused by various reasons result in many casualties and losses. Environmental pollution, which is one of the most important problems of today, and the further recycling of wastes are also benefited by the use of industrial glass, plastic and aluminum additives as products with high added value. It is seen that with the use of the concrete material proposed in the developed project in the column parts of the buildings, it will contribute to both the society and the construction economy, sustainable cities and sustainable development goals within the scope of responsible consumption.

5. Suggestions

Within the scope of the project, a new concrete system was proposed by adding waste glass, plastic and aluminum in different forms in order to increase the resistance of the column parts of the buildings against impact. In the future works of the project;

- Waste glass used as the first additive material in the project can be grinded in different sizes and the effect of the particle sizes on the impact resistance can be examined.
- By changing the aluminum bending diameters, different sizes of aluminum can be placed in a different order other than the honeycomb pattern, and the effect on the strength can be examined.
- The effect on strength can be examined by changing the lower and upper concrete heights of the additive concrete samples. In particular, the strength of the substrate can be strengthened by experimenting with different reinforcement arrangements and concrete contents.
- The effectiveness of new test samples made from waste paper and similar wastes can be examined.
- With the interaction of the industrial establishments, where waste glass, plastic and industrial aluminum waste plates and beverage boxes arise, and the construction sector, these high amounts of waste accumulated in factories can be used in large-scale constructions and their effectiveness can be examined.

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【評語】180016

Complete and large amount of work in engineering tests。Good understanding of the important factors in material strength but weak in innovation.

Strength:

(1) The study is commendable for producing eco-friendly and cost-effective concrete materials through the utilization of industrial waste such as glass, aluminum, and plastic additives. It reveals a significant improvement in concrete resistance to high pressure, coupled with a reduction in surface height changes following an impact.

(2) The strengths of the developed materials were analyzed, providing insights into the experimental methods, and the interpretation of results would add depth to the research. It alludes the potential impact on reducing costs related to waste material disposal and preventing the loss of life and property due to effects and explosions.

Weakness:

(1) Elaborate on the experimental setup for steel fiber concretes with waste glass, aluminum rings, discs, beverage cans, and plastic bottle additives. Including numerical data or graphs illustrating differences in strength and impact resistance would strengthen the research.

(2) Discuss the broader implications for sustainable development goals and consider emphasizing how the present study's findings contribute to the construction sector of environmental sustainability and responsible resource management.

(3) Provide specific examples of how the developed concrete samples outperform or offer advantages over existing construction methods. Include comparisons in terms of strength, cost-effectiveness, and case of production.