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# Gamma Radiation as a Recycling Tool for Waste Materials Used in Concrete

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**Abstract:** This particular review paper considered the use of gamma radiation as a tool for structural modification of recovered materials from waste and its use for preparing concrete. The use of gamma radiation to enhance the mechanical properties of concrete as well as the reuse and recycling of waste materials have been taken into consideration. Reinforced concrete is now crucial to the technological advancement of the building sector. Major engineering projects and general construction frequently employ it. Numerous significant technological developments have helped to create stronger, more effective materials that offer great advantages. Most often, after a very brief period of usage, these things degrade the environment by becoming garbage. Due to this circumstance, there is now a major environmental problem on a global scale. Investigations should have concentrated on recycling utilizing cutting-edge and healthy technologies, such as gamma radiation, as an alternative to traditional mechanical and chemical recycling techniques in order to tackle this issue, promote sustainable development, and reduce environmental pollution. The mechanical qualities of concrete, such as the compressive strength and elastic modulus, are increased by the inclusion of waste particles and the use of gamma radiation, which are effective instruments for reusing and recycling waste materials.

**Keywords:** Waste Materials, Gamma Radiation, Concrete, Recycling, Mechanical Properties

## 1. Introduction

Concrete is a multi-phase material often used as the structural material for the storage and disposal of radioactive wastes [1]. For thousands of years, cement and concrete have been used in various forms. Early cement and concrete constructions, like the Pantheon in Rome, are still standing, demonstrating the reliability and durability of the materials when they are properly formulated, produced, and installed. A solid empirical understanding of the system has been achieved by an in-depth investigation of the characteristics of cementitious materials and data from historical constructions. This knowledge, along with the substance's reasonable cost, makes it an excellent choice for usage in the nuclear sector. The industry uses cement and concrete in a wide range of applications. In this way, concrete serves as shielding in nuclear reactors and is employed as a general building material in addition to being used to encapsulate specific forms of Intermediate Level Waste (ILW) [2, 3].

Manufacturers are interested in developing methods to lessen the environmental impact of industrial processes through reductions in the number of residues produced or by treating those that are inevitably generated as a result of more stringent environmental legislation and market demand for environmentally friendly products. The use of industrial and domestic wastes as alternatives to or complements of fresh materials in a variety of production processes is well-motivated by the environmental harm that is produced during the extraction of raw materials as well as the high cost of extraction techniques. The need to find ways to repurpose waste materials is further encouraged by the depletion of dependable, secure raw material stocks and the need to protect nonrenewable resources [4].

Several tools and approaches have been put forth in recent years to address environmental challenges within the building industry, including a) increasing the use of waste materials, especially those that are by-products of industrial processes; b) using recycled materials in place of natural resources, which will make the industry more sustainable; and c) improving durability as well as mechanical and other properties, thus reducing the volume of construction replacement materials [4]. Recycling which is regarded as the third most preferred waste disposal option, with its numerous environmental benefits, stands as a viable option to offset the environmental impact associated with the construction industry [5].

In theory, ionizing radiations like gamma radiation, X-rays, and electron beams can be used to change the molecular structure of composite materials. Radiation can cause polymer degradation by chain scission and cross-linking. The degree to which these activities take place is primarily determined by the chemical makeup of the polymer [6]. With the help of gamma radiation, recovered scrap polymer can be cross-linked to create materials with improved characteristics. From an economic, ecological, and environmental standpoint, the use of radiation technology in the recycling of polymers is a suitable option [4, 7].

This chapter demonstrates how gamma radiation combined with waste and recycled materials can offer different methods for enhancing the physical and chemical qualities of concrete. The physicochemical alteration of waste materials, such as Polyethylene Terephthalate (PET) bottles, tire rubber, and cellulose in Tetra Pak containers, and their usage in strengthening the qualities of concrete, are reviewed. Such consideration is centered on ways to help improve environmental protection [4, 8].

## 2. Carbon Emissions in the Cement Industry

Concrete is the most widely used construction material that is caused of its excellent mechanical and durability properties [9-11]. Concrete is the most often utilized structural material in the world due to its simple preparation and low cost [4, 12]. Concrete is the second most frequently used material on Earth, right behind water. The cement industry is a crucial sector in the effort to reduce greenhouse gas emissions because it produces around 5% of the world's anthropogenic carbon dioxide emissions [13].

The aggregate for concrete, however, is made up of rocks with various origins, compositions, and textures. Those rocks are separated into magmatic (igneous), sedimentary, metamorphic, and ore rocks based on where they came from. In addition to silicate minerals like those found in granite, granodiorites, liparite, and sandstones, rocks may also contain oxide minerals like hematite and magnetite as well as carbonate minerals like those found in limestone and dolomite. Each rock has a unique texture depending on where it came from and how it was formed. Because there are so many different factors at play, it is difficult to comprehend how rocks react to irradiation. However, it is possible to deduce how irradiated rocks behave from their response to their mineral composition as well as other factors like the texture and origin of the rock [14].

## 3. Recycled and Waste Materials Used in Concrete

The use of waste materials in industrial operations is an appealing area of potential given the increased awareness of environmental issues. Recovering and recycling solid waste can help to solve waste disposal problems while also reducing environmental damage. [4, 5]. The chemical composition of solid waste is used to categorize it as organic or inorganic. The main components of inorganic solid waste include glass, ceramics, and metals used in packaging, such as aluminum. Other materials include zinc, copper, and iron [15].

One of the seven tenets of sustainable building is the use of recycled materials. The International Council of Buildings established these guidelines based on resource efficiency in 1994. Recycling materials can be used in place of primary raw materials in the production of cement and concrete. Examples include recycled concrete aggregate, recycled brick aggregate, waste glass from municipal garbage, and recovered waste gypsum from gypsum boards. The production of cement and concrete is wholly dependent on natural resources [9].

Over the past six decades, the global production of concrete has expanded by a factor of twelve. Today, on average, one ton of concrete is produced annually by every person on the planet. On the one hand, using recycled materials in the production of cement and concrete helps to lower the number of raw resources and urban land use. On the other hand, the qualities of the finished product are influenced by the recycled materials utilized in part replacement of raw materials [9].

Polyethylene terephthalate is one of the most representative elements of organic solid waste (PET). 250 million bottles made up the yearly PET use over the world in 2007 (10 million tons of waste). Every year, 50,000,000,000 bottles are dumped in landfills in the United States [4, 16]. According to the world bank statistics on solid waste management, the world cities are currently generating about 1.3 billion tons of solid waste per year and this volume is that of $CO_2$, besides, composting and burning certain wastes is prohibited by legislation [5].

PET waste can linger in the environment for hundreds of years since it is not biodegradable. Glycols and dibasic acid can be used to create an Unsaturated Polyester Resin (UPR) from PET waste. High compressive strength Polymer Concrete (PC) can be created using this substance as a binder. The higher compressive strength of polymer concrete can be attained with a PET/glycol ratio of 2:1 [4, 16].

The collection of enormous volumes of wasted tires has turned into a significant waste management issue as a result of the rising number of cars on the planet. About 275 million scrap tires were produced in the United States, 110 million in Japan, and 37 million in the United Kingdom in 2002. Taiwan produces more than 100,000 tons of trash tires each year. The final disposition of worn tires is a significant environmental issue; tire dumps provide serious fire and health risks [4].

One of the most popular techniques for getting rid of tire waste is burning tire scrap to generate energy for the creation of vapor or electricity. Waste tires are now regularly used in cement furnaces in the United States and Europe. The bituminous hot mixing of pneumatic dust for agglutinative modification in asphalt pavement is one application that makes use of scrap tires. Its use as a concrete's fine or coarse aggregate replacement is an additional option. Its qualities can enhance concrete's mechanical properties over those provided by sand or stone, such as strength and elastic modulus [4, 7, 9].

Recycling used tires in the building sector can help to reduce environmental pollution and create more cost-effective structures. In this regard, the usage of used tire rubber in ready-mixed concrete has grown significantly over the past two decades, attracting major scientific attention across the globe. To protect marine platforms from the shock of hitting waves or ships, a small amount of unprocessed scrap tires is employed. Tire burning is still practiced in some parts of the world, which contributes to intolerable pollution levels. Therefore, it is crucial to promote recycling using fresh and creative methods. Many nations restrict or discourage the storage of used tires in landfills, which is a strong incentive to look into recycling methods. One of these methods entails turning used tires into alternative aggregates, increasing economic value while lowering aggregate consumption [4, 15, 17, 18].

Rubber from tires is used to make Asphalt Rubber (AR) pavement as well as a variety of elastomers and plastic products. A binder for rubberized concrete mixtures is oxychloride cement. An open gradation method and a gap-graded design were both used to prepare asphalt rubber in a recent study. The performance was satisfactory, and home usage was possible, according to the results. The wet method is best for regular asphalt mixtures containing Ground Tire Rubber (GTR). It's important to note that rubber asphalt mixtures adhere to ASTM International standards (formerly the American Society for Testing and Materials). Modified asphalt can be a better option than traditional mixtures for the use of regional materials and paving methods by using various AR and GTR concentrations [4, 15, 18, 19].

The mechanical characteristics of reinforced epoxy powder tire rubber-based polymer concrete were investigated in a review study. Mixtures were cost-effectively optimized utilizing direct neural modeling and reverse neuronal modeling; in this situation, resin content is the key cost factor. The mixture that produced the highest values of compressive, flexural, and tensile strength was determined using direct neural modeling. The highest values of mechanical attributes obtained with different epoxy resin powder concentrations were analyzed using reverse neural modeling. The findings indicate that a composition containing 0.3 (weight percent) of tire powder and 0.215 (weight fraction) of epoxy resin exhibits strong resistance to compression. Tire powder epoxy and 0.17 resin were used to achieve the highest flexural strength of 0.23 and the highest tensile strength of 0.24, respectively [4, 20].

The concrete's compressive strength is decreased when tire rubber is used as an aggregate, which may affect the concrete's usefulness in some structural applications. Despite this, it possesses advantageous qualities such as decreased density, increased impact resistance and toughness, increased ductility, and superior sound insulation properties. These attributes could be useful in a range of construction applications, like access roads. Using scrap tires to create concrete-coated tire rubber particles could significantly reduce the amount of garbage produced by used tires. Magnesium oxychloride can be used to create high-strength concrete with much superior performance and better elastomer adhesion qualities [4, 20].

Additionally, the preparation of the tire rubber aggregates with magnesium oxychloride may increase the adhesion of tire rubber particles to other constituent concrete elements. Size and concentration of tire particles, cement type, the use of chemical and mineral additives, and tire rubber particle pretreating techniques are some of the variables that affect adhesion. Tire powder can be used in mortars and concrete, depending on the size. Additionally, compared to plaster without additives, plaster with increased textile fiber content (from recycled tires) results in less resistance reduction. Composites contain a variety of waste products, such as recycled tire fibers, granulated cork, and cellulose fibers from discarded paper. Numerous studies have focused on creating new composite materials using various composite production procedures, such as straightforward molding or pressing [4, 20].

Natural fibers mostly consist of cellulose, hemicellulose, and lignin, with trace amounts of pectin, wax, and water-soluble compounds. A crystalline structure is created when hydrogen bonds between linear cellulose molecules join them laterally to form linear bundles. One of the most crucial cellulose structural factors is the degree of crystallinity. As the ratio of crystalline to amorphous regions rises, cellulose fibers become more rigid and less flexible. Additionally, the addition of cellulose fibers enhances the composites' ability to bend [4].

Cellulose-containing waste items, such as Tetra Pak containers, are among the most significant. Three raw components are used to create this packaging: paper (approximately 75% of the total), low-density polyethylene (about 20%), and metal (about 5 percent). Hydro pulping is a straightforward, well-known method for recycling used containers. The cellulose fibers are isolated from microscopic layers of polyethylene and aluminum during this procedure [4, 5].

Paper Sludge (PS), the majority of the waste produced by the paper industry, is burned to produce PS ash. It is a raw material for cement as well as a tool for improving the soil. PS ash's strong water absorption ability contributes to the strength of highly stiff concrete. When added to concrete, it goes through a pozzolan reaction with calcium hydroxide as a result of the cement's hydration, producing a material with higher compressive strength than concrete without PS ash. 38.1 percent of the substance is silica ($SiO_2$), 21.4 percent is alumina ($Al_2O_3$), and 28.9 percent is calcium oxide (CaO).

There are no spherical particles visible in the Scanning Electron Microscopy (SEM) photos of PS ash, only particles with a rough form. 200 $kg/m^3$ of cement and 100 to 300 $kg/m^3$ of PS ash are typical concentrations. In cement matrices, plant fibers and "man-made" cellulose fibers are used to replace asbestos fibers because they exhibit similar properties at a cheaper cost, with values largely based on the characteristics of the fiber and the degree of adhesion between the fiber and matrix [4, 15].

Paper recovered from packaging has been used to create composite materials, and the pulped fibers are made up of 40% resinous wood, 35% Alfa grass (Stipa tenacissima L.), and 25% leafy wood. For values below 1.25 mm, the fiber diameters are categorized as fine, and for values between 1.25 mm and 5 mm, as coarse. The findings indicate that compressive strength falls as pulped fiber content increases, mostly because more voids are created as fiber content rises, reducing weight and weakening the composite. Calculating the water/cement ratio (W/C) is important because adding waste fibers to cement increases the amount of water needed for the preparation to make up for the water the fibers absorb. Images from SEM microscopy for a composite containing 10% fibers (W/C = 0.56) reveal fiber agglomerations in non-homogeneous dispersion. Better fiber dispersion is shown when more water is introduced (W/C = 0.64), but strength is reduced due to the voids that the extra water creates [4, 5, 15].

When cellulose fibers (2–16 percent by weight) are added to composites, the thermal conductivity values drop, which results in energy savings. Thermal conductivity is a measurement of a material's ability to resist heat flow. Thus, the fibers are utilized as a cement substitute. This behavior is brought on by both the insulating qualities of the fibers themselves and the porosity that develops in the packing of fibers as a result of air bubbles created during the mixing process. A composite specimen is made lighter and has less thermal conductivity when there are more voids in the mixture [4].

In place of cement, cellulose fibers from recycled packaging have been utilized in lightweight concrete at concentrations of up to 16 percent by weight. According to study findings, using the right amount of water and cement, adding more fiber to concrete decreased its compressive strength and improved its thermal insulation capabilities while also ensuring that the fibers were distributed evenly throughout the matrix. Lightweight construction materials are made possible by improved thermal insulation of the cement matrix and low density. Building partition walls (compressive strength 8.6 MPa), partitions, ceilings, and roofs use this form of lightweight concrete [4].

The use of PET materials as a concrete aggregate substitute is a significant recycling alternative. Studies are looking at the possibilities of creating alternative materials with greater usefulness, lower cost, and superior physical, chemical, and mechanical qualities than those of standard materials given the technical needs in the building industry [4, 16].

Due to the enhanced properties of these materials, virgin polymers used in road surfaces have demonstrated advantages over the past 20 years. Researchers have employed several polymers that, when correctly combined with asphalt, have increased the production and longevity of road surfaces. Waste polymers, however, can be harmful and continue to pollute the environment, thus they must be successfully recycled or repurposed [4, 7].

The asphalt can be altered with a variety of compounds, the majority of which are rare and expensive virgin ingredients, to increase the yield of the road surface. Utilizing waste products, such as plastic bottles, as an alternative might help minimize waste and possibly increase yield. The usage of PET fibers from plastic bottles has increased the ductility of concrete. The findings reveal that even a small amount of fibers can significantly affect how concrete behaves after cracking. Both type O and type lamellar fibers increase the hardness of concrete. The latter aids in fusing the sides of each cracked area of concrete together [4, 16].

Through short-term creep experiments, numerous researchers have forecast the long-term creep of polymer concrete containing $CaCO_3$, fly ash, and recycled PET resin. According to the results, PET causes early-age concrete to creep more quickly than regular concrete does. The first two days account for more than 20% of the long-term creep, and the first 20 days for 50%. Additionally, due to the increased surface area of the $CaCO_3$ particles, creep deformation of polymer concrete without reinforcement is greater than that of concrete with $CaCO_3$. To minimize the deformation of polymeric concrete, reinforcement is crucial. Due to the viscoelastic, non-linear nature of polymeric concrete with recycled PET materials, the creep values increase with an increase in applied effort, however, the increases are not proportional [4, 16].

Up to 3% of recycled PET bottle fibers have been used in the production of concrete. Alkali strength is the key challenge in the creation of PET fiber, although research has shown that this is not a problem for fiber used in concrete. PET fiber has been utilized for covering and pulverizing tunnels, particularly those for motorcycles. Future uses could include difficult environment underground constructions, such as those located by the water or close to the coast. Additionally, it can be used as pavement on curvy, steep, and narrow roadways. PET fibers were found to have lower moisture levels than Polyvinyl Alcohol (PVA) fibers but greater moisture levels than Polypropylene (PP) fibers in a study comparing PET with other fibers [4, 16].

Concrete fractures were lessened by the addition of PET particles made from recycled bottles. These particles had lengths of 10, 15, and 20 mm and concentrations of 0.05, 0.18, and 0.30 percent by volume. At 28 and 150 days, tests for bending and impact were conducted. With the inclusion of fiber, significant changes in compression strength values were seen. Additionally, increasing fiber content resulted in lower Young modulus values, with surface changes occurring following the increase in fiber concentration [4].

PET concentrations affect concrete's compressive strength.

In terms of the surface properties of concrete with PET particles, this behavior can be described. Sand and gravel aggregate distributed particles exhibit rough surfaces in concrete devoid of PET particles (0 percent PET). PET particles cover the mineral aggregates in lower quantities, and rougher surfaces are visible (1.5 percent PET). With higher PET particle concentrations, the surface morphology of concrete changes, becoming more homogeneous and containing certain compact zones (2.5 percent PET). However, regions with some cracks are seen when PET particle concentration is further raised (5.0 percent PET) [4, 16].

In a different study that looked at curing time, it was found that the presence of fibers at 28 days boosted flexural, impact, and tensile strength. Due to fiber deterioration and fragilization in the alkaline concrete environment, this improvement, however, was no longer visible by 150 days. Fibers were added to concrete to increase porosity after a year. The utilization of recycled resources in construction is one of the crucial parts of sustainability, and recycled PET bottle fibers offer an alternative to reinforced concrete [4].

# 4. Structural Modification of Waste Materials Using Gamma Radiation

When radioactive atomic nuclei break apart and when some subatomic particles decay, gamma rays are created. There is some wavelength overlap in the generally recognized classifications of the gamma-ray portion of the electromagnetic spectrum. The wavelengths of gamma radiation are often less than a few tenths of an angstrom, while the photon energy of gamma rays is more than tens of thousands of electron volts [4]. Since photons are neither massless nor chargeless, they can penetrate materials and the atmosphere far more deeply than alpha and beta radiations [14].

Typically, alterations in polymers' chemical structure and mechanical behavior are used to assess the effects of gamma radiation on those materials. Chemical bonds are reorganized as a result of these alterations, which allows for greater structural reticulation or polymerization. In order to enhance their characteristics and increase their compatibility with composite materials, polymers have been changed [4, 7].

Currently, gamma radiation is being used successfully for the recycling of post-consumer plastics. Such technology is feasible from an economic and environmental perspective. The following are a few of this application's most significant advantages: A more rapid polymer decomposition, particularly by chain scission, which produces low molecular masses that can be used as additives or raw materials in various processes; b) more advanced polymeric materials production, specifically created to be environmentally friendly [4, 18]; and c) improvement in mechanical properties and performance of recovering polymers or polymer mixtures, primarily through cross-linking or modification of several combined-phase surfaces [7].

In numerous types of researches, the effects of gamma radiation on PET have been examined. For instance, Electron Spin Resonance (ESR) and optical absorption spectroscopy were used to evaluate the processes involved in PET degradation brought on by radiation. PET films were exposed to radiation in the dark at a temperature of 196 °C. The film turned reddish-purple after exposure to radiation, allowing ESR to detect PET radical ionic species. Another study used gamma radiation to undertake a photosensitization procedure. The results were monitored using reversed-phase high-performance liquid chromatography and infrared spectroscopy. The generation of terephthalic acid as a result of radiolysis and PET break zones were both noted [4, 16].

Diethylene glycol concentration rises at low doses (5-10 kGy), but falls at high doses (30-200 kGy), according to studies on the effects of gamma radiation on PET packing films in the 0-200 kGy dose range. At dosages larger than 60 kGy, molecular mass, intrinsic viscosity, and terminal carboxyl groups all see a modest drop; nonetheless, permeability, thermal characteristics, color, and surface resistivity are unaffected at any dose [4]. SEM was used to analyze the morphology of the surfaces of recycled PET particles, which ranged in size from 0.5 to 3.0 mm and were produced by cutting PET bottles [15, 16].

For dosages up to 3.5 MGy at a rate of 28 kGy/h, the thermal behavior of gamma-irradiated amorphous PET films under ambient circumstances was investigated. The glass transition temperatures (Tg) and levels of crystallinity were calculated using Differential Scanning Calorimetry (DSC) [21]. The findings demonstrated that as the dose was raised, both Tg and heat capacity dropped, which was caused by polymeric chain breaking mechanisms. It is conceivable to draw the conclusion that Tg could be utilized as a dose absorption ratio indication in PET [4, 16].

The effects of gamma radiation on PET were assessed by DSC, X-ray photoelectron spectroscopy, SEM, and molecular mass determination at doses up to 15 MGy at a rate of 1.65 MGy/h. At a dose of 5 MGy, a drop in molecular mass was seen, which was attributed to polymer chain scission; however, at doses higher than 5 MGy, molar mass rose, primarily because of recombination and branch creation [4, 15].

In order to assess the optical and structural characteristics of irradiated PET in the 0–2 MGy dosage range, X-ray diffraction and UV spectroscopy were used. The semi-crystalline character of PET was revealed by the diffraction pattern, with crystallinity increasing with radiation exposure. The prohibited band shrank at higher applied doses, according to UV analysis, while both activation and absorption energies increased. In a different investigation, PET bottles were exposed to radiation at doses ranging from 0 to 670 kGy. The results revealed a rise in crystallinity and crystal size in the produced particles [4, 16].

Using applied dosages of 25, 50, and 100 kGy, the effects of gamma radiation on the mechanical and thermal properties of recycled PET mixes with Low-Density Polyethylene (LDPE) and Ethylene Vinyl Acetate (EVA) were investigated. The results showed that 10% of recycled PET that was irradiated at 100 kGy produced the greatest cross-linking chains. Gamma radiation was used to graft an ethylene-methyl-acrylate-glycidyl methacrylate monomer onto PET. Compared to the non-irradiated mixture, the produced elastomer demonstrated a 30% increase in impact strength with only 0.1 percent terpolymer mass. These findings support the notion that gamma radiation is a particularly effective method (on-site) for increasing the compatibility of polymers in composites [4, 7, 16].

When exposed to radiation doses up to 1 MGy, a study of thermoplastic aromatic polyesters (used for their electrical insulating capacity) revealed stable polymeric chains because of the presence of benzene rings. Irradiated PET samples exhibited a reduction in molecular mass due to chain scissions for higher doses (5 MGy) [4].

According to certain studies on the effects of gamma radiation on the physicochemical characteristics of cellulose, an increase in the dose of 25 kGy (on average) resulted in a loss of 1% in cellulose crystallinity in the dose range of 0–1 MGy. Up to 31.6 kGy, cellulose degrades (from 6 to 12 percent), while up to 300 kGy, the degree of crystallinity is unaltered. Up to 1 kGy, the degree of polymerization (DP) is obtained; over 10 kGy, these decreases. Additionally, variations in specific gravity and lattice constant are seen up to 1 MGy, with cellulose completely degrading around 6.55 MGy [4, 22].

Along the microfibril length of cellulose, there are amorphous zones where the crystallinity is broken. Chemicals can enter the microfibrils through these zones. Additionally, cellulose is broken down by gamma radiation into shorter chains that are water-soluble as well as an "opening of new micro-cracks" that are easily accessed by water molecules [4, 22]. Smooth and homogenous surfaces as well as some particles are seen in unirradiated cellulose. At 50 kGy, there are more dispersed particles and some cracks visible; at greater doses, there is more space between the cellulose surfaces as well as a few microscopic gaps. These alterations can be linked to the primary gamma radiation impacts, which include the scission and cross-linking of cellulose's molecular chains [4].

Particles that have not been exposed to radiation exhibit a homogeneous surface, but those that have undergone a 200 kGy dose exhibit voids and surface roughness. Gamma radiation dosages that are increased result in greater surface damage and the formation of voids (larger than 100 m). Finally, with radiation at 300 kGy, the surface damage is more obvious and exhibits significant gamma radiation-induced fissures [4, 23].

## 5. Concrete with Waste and Recycled Materials: Effects of Gamma Irradiation

Utilizing gamma radiation has substantial benefits for recycling PET and enhancing the mechanical qualities of concrete, which can be attributed to alterations in the chemical composition of the surface. Gamma radiation can have many advantages, the most significant of which is improved adhesion between the fibers and matrix. Gamma radiation increases the commencement of polymerization of a monomer into the ceramic matrix. Concrete's strain, compression, and impact strengths, deformation at the yield point and breakdown, deformation values, and elasticity modulus are its primary mechanical properties that are examined [4, 16].

Gamma radiation is used to recycle materials and enhance the mechanical qualities of concrete. These benefits are explained by changes in the chemical structure of the surface. Gamma radiation has the ability to produce significant advantages by accelerating the initiation and polymerization processes of a monomer into the ceramic matrix. Improved adhesion between polymers and the matrix is the most crucial. Concrete's strain, compression, and impact strengths, deformation at the yield point and breakdown, as well as the deformation values and elasticity modulus, are the key mechanical parameters that are examined [24].

Ionizing radiation's effects on composite materials made of polymer and ceramic have been the subject of some studies. For instance, the polymerization yield in gypsum/poly (methyl acrylate) composites grew as the radiation dose did. At dosages of 3–4 kGy, a yield of 87–88% was achieved. Since the process is carried out at room temperature, there is a significant saving in heat energy in addition to a decrease in the price of maintaining the pressure on the composite. When creating a ceramic-polymer composite, the pressure enables a significant amount of the monomer (which is often very volatile) to fill the gaps in the ceramic matrix [4, 23].

The impact of gamma radiation on concrete has been the subject of a few investigations. By using the proper radiation dosages, the consequences generated can be managed. For example, the surface can be changed to produce a material that is rougher and more fractured, allowing for higher compatibility with the cementitious material [4].

Similar patterns in compressive strength values were seen for concrete that contained irradiated scrap tire particles. The values ranged from 7.4 to 17.5 MPa and decreased as particle concentration rose. The highest value was for concrete containing 10% of 2.8 mm-sized particles; this value was 27% lower than that of the control concrete. Concretes with 2.8 mm-sized particles exhibited higher values than concretes with 0.85 mm-sized particles. When compared to concrete with non-irradiated particles, the concretes with 20 or 30 percent of particles showed greater values. Employing larger particle sizes is therefore more effective than using smaller ones [4].

The size and quantity of the discarded tire particles affect the concrete's mechanical qualities. The presence of these particles lowers concrete's compressive and tensile strengths because they encourage stress concentration zones and create tensile stresses that cause concrete to break and crack quickly. However, in some instances, gamma radiation treatment of the waste tire particles results in an improvement in mechanical qualities. It seems that concrete with 2.8 mm-sized, 10%-irradiated particles produces the greatest results. Up to 30% of tire particles can be added to concrete with irradiation particles, which helps to lower the final cost of the concrete [4, 15].

# 6. Conclusions

When waste materials are used in place of sand in concrete, gamma radiation, waste materials, and recycled materials can all be effective instruments for enhancing the material's mechanical qualities [5]. In particular, when a given concentration of waste materials is added and a certain amount of gamma radiation is applied, the values for compressive strength and elastic modulus improve. Contrarily, non-irradiated concrete performs poorly mechanically compared to irradiated concrete [23].

Gamma radiation and waste materials, where waste materials are substituted for gravel or sand, are both helpful methods for enhancing the mechanical qualities of concrete. With specific waste material addition concentrations and a particular dose of gamma radiation, in particular, the compressive strength and modulus of elasticity values show improvement. Non-irradiated concrete, on the other hand, has subpar mechanical qualities.

Waste materials of various shapes (particles or fibers) may be appropriate as a construction material since concrete compressive strength is a crucial structural design criterion used by engineers. To improve the mechanical qualities, a small proportion of waste materials might be used in place of fine aggregates in the mix design. Gamma radiation can also be a practical tool and appropriate process for recycling waste materials [17]. Waste concentrations affect the flexural and compressive strength properties. When the waste concentration is high enough to reduce the detrimental effects of inadequate particle-matrix adhesion, mechanical characteristics often improve. Gaining ductility comes at the expense of compressive and flexural strength [22].

Compressive strain normally rises steadily with increasing PET particle concentration in concrete with non-irradiated samples, although compressive strength and elasticity modulus are unaffected by variations in concentration. Maximal values of compressive strength and elastic modulus are both dependent on PET particle size in terms of PET particle size. For irradiated versus nonirradiated concrete, different behaviors are seen. Compressive strength values decrease as PET concentration rises. The decrease in compressive strain is more striking. The elasticity modulus, however, behaves in the opposite way to that of unirradiated concrete. The action of gamma radiation on waste materials and its impact on the mechanical qualities of concrete is further supported by SEM images [14, 15, 22].

# References

[1] M. Robira, B. Hilloulin, A. Loukili, G. Potin, X. Bourbon, A. Abdelouas. (2018). "Multi-Scale Investigation of the Effect of Γ Irradiations on the Mechanical Properties of Cementitious Materials", Construction and Building Materials.

[2] Alexander J Potts. (2021). The Assessment of Gamma Radiation on the Properties of Structural Concrete, PhD dissertation, University of Manchester.

[3] Maxime Robira, Benoit Hilloulin, Ahmed Loukili, Gaël Potin, X. Bourbon, et al. (2018). Multi-scale Investigation of The Effect Of Γ Irradiations on The Mechanical Properties of Cementitious Materials. *Construction and Building Materials,* Elsevier, 2018, 186, pp. 484-494, 10.1016/j.conbuildmat.2018.07.038.

[4] Gonzalo Martínez-Barrera, *et. al.* (2015). Gamma Radiation as a Recycling Tool for Waste Materials Used in Concrete, http://dx.doi.org/10.5772/60435.

[5] Oriyomi M. Okeyinka, David A. Oloke, and Jamal M. Khatib, (2015). A Review on Recycled Use of Solid Wastes in Building Materials, World Academy of Science, Engineering and Technology International Journal of Civil and Environmental Engineering Vol: 9, No: 12.

[6] Aliyu Usman, Muslich Hartadi Sutanto, Madzlan Napiah. (2018). "Effect of Recycled Plastic in Mortar and Concrete and the Application of Gamma Irradiation - A Review", E3S Web of Conferences.

[7] A Cesur, NU Kockal. (2019). Effects of Gamma Irradiation on Polymer-Modified Concrete (PMC): *A Review Cur Trends Civil & Struct Eng.* 3 (3): CTCSE. MS. ID.000563. DOI: 10.33552/CTCSE.2019.03.000563.

[8] Ehab E. Khozemy, H. Radi, and Nabila A. Mazied. (2022). Upcycling of Waste Polyethylene and Cement Kiln Dust yo Produce Polymeric Composite Sheets Using Gamma Irradiation, *Polymer Bulletin,* https://doi.org/10.1007/s00289-022-04310-2.

[9] Tereza Pavl. (2018). The Utilization of Recycled Materials for Concrete and Cement Production- A Review, *IOP Conf. Series: Materials Science and Engineering 442*, doi: 10.1088/1757-899X/442/1/012014.

[10] Miguel Mart´ınez-L´opez *et al.* (2015). Waste Materials from Tetra Pak Packages as Reinforcement of Polymer Concrete, *International Journal of Polymer Science,* Volume 2015, Article ID 763917, http://dx.doi.org/10.1155/2015/763917.

[11] Tereza Pavlů. (2018). "The Utilization of Recycled Materials for Concrete and Cement Production- A Review", IOP Conference Series: Materials Science and Engineering.

[12] Carolyn E. Schaefer, Kunal Kupwade-Patil, Michael Ortega, Carmen Soriano, Oral Büyüköztürk, Anne E. White, Michael P. Short. (2018). "Irradiated Recycled Plastic as A Concrete Additive for Improved Chemo-Mechanical Properties and Lower Carbon Footprint", Waste Management.

[13] Schaefer, C. E., et al. (2017). Irradiated Recycled Plastic as A Concrete Additive for Improved Chemo-Mechanical Properties and Lower Carbon Footprint, *Waste Management*, https://doi.org/10.1016/j.wasman.2017.09.033.

[14] Mustafa Hameed Alsaid (2017). Toward the Understanding of Irradiation Effects on Concrete: The Irradiated Minerals, Aggregates, and Concrete Database, MSc Thesis, University of Tennessee, Knoxville.

[15] G. Martínez-Barrera *et al.* (2020). Waste Tire Rubber Particles Modified by Gamma Radiation and Their Use as Modifiers of Concrete, Case Studies in Construction Materials 12 (2020) e00321.

[16] Usman, A.; Sutanto, M. H.; Napiah, M.; Zoorob, S. E.; Yaro, N. S. A.; Khan, M. I. (2021). Comparison of Performance Properties and Prediction of Regular and Gamma-Irradiated Granular Waste Polyethylene Terephthalate Modified Asphalt Mixtures, *Polymers*, 13, 2610. https://doi.org/10.3390/polym13162610.

[17] Nikola Tošić, Jelena Dragaš, and Vedran Carević. (2016). Use of Recycled and Waste Materials in Concrete a Serbian Perspective, *Conference Paper,* https://www.researchgate.net/publication/304498237.

[18] de la Cruz, J. M. C., Guzman, C. G., Mejia, F. C., Acevedo, B. L., Cedillo, O. F., de Buen, I. G., Ocampo, A. M. and Valencia, H. M. (2021). Effect of the Substitution of Sand by Rubber of Waste Tires on the Mechanical Properties of Hydraulic Concrete and Exposure to Gamma Radiation, *Journal of Minerals and Materials Characterization and Engineering*, 9, 245-256, https://doi.org/10.4236/jmmce.2021.93017.

[19] EL. Sayed Fathy EL. Sayed. (2010). Recycling of Some Polymeric Wastes Using Ionizing Radiation, MSc Thesis, Zagazig University 1995, National Centre for Radiation Research and Technology (NCRRT), Atomic Energy Authority.

[20] G. Martínez-Barrera *et al*. (2019). Modified Recycled Tire Fibers by Gamma Radiation and Their Use on The Improvement of Polymer Concrete, *Construction and Building Materials 204*, 327–334.

[21] Munzer Kattan. (2006). "Thermal Behavior of Gamma-Irradiated Amorphous Poly (Ethylene Terephthalate) Films", Polymer Engineering & Science.

[22] Jeon D. H., Lee H. K., Park H. J. (2003). The Effects of Irradiation on Physicochemical Characteristics of PET Packaging Film, *Radiation Physics and Chemistry 2004*; 71: 1059–1064, 10.1016/j.radphyschem.2003.10.009.

[23] Siddhartha S. A., Kapil D., Suresh-Kumar R., Krishna J. B., Wahab M. A. (2012). Effect of Gamma Radiation on The Structural and Optical Properties of Polyethyleneterephthalate (PET) Polymer, *Radiation Physics and Chemistry 2012*; 81 (4): 458–462, 10.1016/J.RADPHYSCHEM.2011.12.023.

[24] Gonzalo Martinez-Barrera, Witold Brostow and Susana Hernandez-Lopez. (2015). Waste and Recycling Materials Used in Concrete, *International Journal of Advances in Science Engineering and Technology*, Issn: 2321-9009, Volume- 3, Issue-3.