J. Res. Technol. Eng. 7(4), 2026, 120-134

Journal of Research Technology and Engineering
www.jrte.org

Application of Recycled Materials in Construction and Selected Engineering Fields

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Received: 28 July 2026; Revised: 30 August 2026; Accepted: 20 September 2026; Available online: 10 Oct 2026

Abstract: The growing need for construction and engineering materials stemming from swift urban growth and industrial progress has led to the overuse of natural resources and heightened environmental worries. The incorporation of recycled materials has garnered considerable interest as a sustainable approach in numerous engineering fields. This research examines the use of recycled materials in fields such as construction, chemical, automotive, marine, electrical, and aerospace engineering. A qualitative literature review was conducted using secondary data from academic publications covering construction, chemical, automotive, marine, electrical, and aerospace engineering. The results of the review suggest that recycled materials contribute to environmental protection, conservation of resources, reduction of waste, and saving of energy. The review indicates that the role of recycled materials varies across engineering sectors, ranging from aggregate and cement substitution in construction to material recovery from end-of-life vehicles and electronic waste, and composite recycling in marine and aerospace applications. The use of recycling technologies in engineering industries encourages the use of sustainable engineering methods and promotes the circular economy. However, the acceptability of recycled materials in engineering industries is limited by factors such as material quality, durability, recycling issues, and regulations regarding the use of recycled materials. To optimize the benefits of recycled materials in engineering industries, as well as to increase the sustainability of these industries, it is recommended that new technologies be continuously developed, quality control measures be implemented, and recycling systems be improved.

Index Terms: Circular Economy, Recycled Materials, Recycling Technologies, Sustainable Engineering, Waste Management.

1 Introduction

The urbanization and industrialization which are currently taking place in the world has led to a rapid growth in the demand for construction and engineering materials. Nowadays, construction operations require vast quantities of natural resources like sand, cement, aggregates, metals and other fundamental supplies to build infrastructure consisting of roads, bridges and buildings. However, that the ongoing extraction and use of these natural resources contributed to serious environmental problems, including depletion of resources, pollution and escalating carbon emissions. These concerns for the environment have led to a crucial to sustainable construction practices in the engineering field. The use of recycled materials in the development and various additional applications in engineering is one of the best solutions. Recycled materials are materials recovered from waste streams and processed for reuse as raw materials, components, or inputs in new products and engineering applications. This helps to reduce problems of waste management and helps to preserve natural resources [1], [2].

Engineered products today utilize many different recycled materials. These include recycled concrete,

recycled steel, fly ash, waste glass, plastic waste and rubber materials. They are used in roads, buildings, pavements, cement production, insulation compound and other structural and non-structural operations. Properly processed, many of these recycled materials can provide acceptable strength and durability. There are numerous benefits of recycled materials. It reduces the amount of waste going to landfills, minimizes environmental contamination, saves energy and encourages sustainable growth. It also reduces the financial burden of construction and makes effective utilization of available resources [1], [2].

But there are also some challenges in the use of recycled materials. They are quality variations of materials, environmental problems and functionality concerning problems that are long lasting. Hence, appropriate tests, processing and quality control are allowable for safe and efficient use in conventional engineering contexts [2]. Accordingly, this review aims to examine the applications of recycled materials across construction, chemical, automotive, marine, electrical, and aerospace engineering, with particular attention to their engineering applications, environmental and economic benefits, technological developments, and implementation challenges. The review further compares these fields to identify common trends, limitations, and opportunities for advancing sustainable engineering and circular-economy practices. In this review, the discussion primarily focuses on recycled and waste-derived materials, while recyclable and bio-based materials are considered where they directly contribute to material recovery, reuse, or circular-economy strategies.

2 LITERATURE REVIEW

The following subtopics discuss the key concepts and previous studies related to this research.

2.1 Construction Engineering

With the rapid growth of the construction sector, the demand for raw materials such as cement, stone aggregate, asphalt, steel and sand has increased significantly. This excessive consumption has contributed to natural resource depletion, waste gathering, air pollution and greenhouse gas emissions. Therefore, researchers and engineers have focused their attention on using recycled materials and waste materials for sustainable construction methods [1], [2].

As Bolden et al point out, recycling construction waste is important to conserve natural resources and reduce waste generation. According to the studies, it has also been discussed that recyclable materials such as recycled concrete aggregate, reclaimed asphalt pavement, fly ash, glass, plastic, rubber, slag and carpet fibers can be successfully used for engineering applications [1].

Recycled Concrete Aggregate (RCA) is a widely used recycled material in the construction industry. RCA is produced by crushing and reusing aggregate from demolished concrete structures. Researchers have shown that RCA can be used in highway construction, drainage systems and concrete production. Studies have shown that recycled concrete aggregate can provide acceptable engineering performance for selected applications when appropriately processed, although its properties may vary depending on the source material, contamination, and processing conditions [2], [3]. However, high water absorption and old debris contamination have been identified as major problems with RCA [2], [4]. Reclaimed Asphalt Pavement (RAP) is another important recycled material widely used in the field of transportation engineering. RAP is obtained by recycling old asphalt pavements. Previous research has shown that RAP has high hardness, good drainage capacity and satisfactory durability. In addition, the use of RAP reduces the need for new asphalt materials and construction costs [1], [3].

Fly ash is a by-product of the combustion of coal in thermal power plants. According to several studies, fly ash can be used as a partial replacement for cement in concrete production. Researchers have shown that fly ash helps to increase the workability of concrete, reduces the water requirements of the concrete, minimizes early age cracking in the concrete, and improves the long-term durability of the concrete. Some studies have shown that fly ash-stabilized soil increases soil strength and reduces swelling in pavement subgrades and foundation materials [2].

Plastic waste is considered a serious environmental problem in the world today because it is not biodegradable. Therefore, researchers have focused on using recycled plastics in asphalt mixtures, paving blocks, insulation products, and soil reinforcement applications. Previous research has shown that the addition of plastic waste increases pavement stability, friction resistance, and adhesion between asphalt and aggregate [1], [2].

Glass waste is another recyclable material that can be used for construction engineering applications. Waste glass is crushed and used as road aggregate, decorative products, and fiberglass insulation materials. However, some studies have shown that the use of glass particles in concrete mixtures can cause problems with alkali-silica reactions and performance [1].

However, previous researchers have identified several challenges related to the use of recycled materials. differences in quality, pollution, lack of awareness, insufficient technical knowledge, and lack of proper regulations are considered to be the main barriers. Some companies do not prefer to use recycled materials due to concerns about durability, environmental hazards, processing costs, and lack of proper testing data. Therefore, the researchers recommended that further studies, better documentation, awareness programs and proper quality control methods are needed [5], [6].

2.2 Chemical Engineering

Growing environmental concerns and the need for sustainable industrial practices have led to increased attention being paid to the use of recycled materials in chemical engineering. Previous studies have also found that recycling technologies improve resource efficiency and sustainable industrial processes. In addition, improving design engineering recycling technologies supports the development of these processes and reduces the costs and resources required for their production [7].

Plastic recycling is a major research area in chemical engineering. Various studies have investigated the conversion of waste plastics into useful industrial products through processes such as extrusion, pyrolysis, and chemical treatment [7], [8]. Recent research has also demonstrated the potential of recycled polyethylene terephthalate (rPET) from post-consumer PET waste as a feedstock for additive manufacturing. Mechanical recycling, involving sorting, cleaning, shredding, drying, and extrusion, can convert PET waste into filament for material extrusion processes, providing an additional pathway for transforming plastic waste into functional engineering products [7].

Chemical engineering researchers have studied the use of industrial by-products such as fly ash, slag, and industrial ash for construction and manufacturing applications. Studies have shown that the use of these waste materials can improve the mechanical and thermal properties of construction products and reduce the environmental impacts of industrial waste disposal. The use of fly ash and slag as supplementary materials in the production of cement and concrete is widely accepted, which increases the durability of the products and improves material performance [1], [2].

Overall, chemical engineering contributes to the utilization of recycled materials by developing and optimizing separation, conversion, and recovery processes. Technologies such as extrusion, pyrolysis, and

chemical treatment can transform waste streams into secondary raw materials and useful industrial products, thereby supporting resource efficiency and circular manufacturing systems [7], [8].

2.3 Automotive Engineering

The automotive industry is an important application area for recycled materials, particularly metals, plastics, rubber, and glass recovered from manufacturing waste and end-of-life vehicles (ELVs). These materials can be reintroduced into vehicle manufacturing to reduce the consumption of virgin resources, minimize waste generation, and support more sustainable production and circular-economy practices [9], [10].

End-of-life vehicles (ELVs) represent an important source of recoverable materials, including metals, plastics, rubber, and glass. Effective dismantling, material separation, and recycling of ELVs can reduce landfill disposal and enable the reuse of recovered materials in vehicle manufacturing. Consequently, ELV management has become an important component of circular-economy strategies within the automotive industry [9], [10].

Among the recycled materials used for this industry, Recycled plastic is a distinctive material. Plastic is used in vehicles mainly because of the reduction in weight. There are several types of recycling methods for plastic, and they are Mechanical recycling, Chemical recycling, Thermal recycling, and Enzymatic recycling. In practice, among these, Mechanical recycling is the most widely used method of recycling because of its energy efficiency and maturity [10]. Studies show that recycled automotive plastics can retain most of their mechanical strength and stiffness after recycling [10]. Steel (from scrapped vehicles and etc..) is a commonly used material in vehicle manufacturing after recycling. Mainly, recycled steel is used in vehicle body panels and chassis and is used mainly because of its ability to retain strength while reducing energy consumption. Recycled Aluminum (from aluminum cans, scrap, and etc) is another material used in the automotive industry, which is mainly used in wheels, engine parts, and lightweight vehicle structures. Recycled rubber (mainly from used tires) is also found in vehicles where they are applied as floor mats, sound insulation, and suspension components, and is useful for reducing the landfill waste [9], [10].

The automotive industry is increasingly adopting circular-economy approaches by recovering materials from end-of-life vehicles and reintroducing them into manufacturing processes. Effective vehicle disassembly and material separation are important for improving recycling efficiency and maintaining the quality of recovered materials [9], [10].

According to the points from the articles, the main environmental benefits of the recycled automotive materials are reducing landfill waste, conserving natural resources and reducing greenhouse gas emissions [9]. When lightweight recycled materials are used in vehicle production, fuel efficiency improves by reducing vehicle weight. If we take the challenges of recycled automotive materials, maintaining proper quality and meeting safety standards remain major challenges, while material sorting and separation are critical for improving recycling effectiveness. Future automotive manufacturing is expected to use more recycled materials to achieve sustainability goals. Advanced recycling, sorting, and material-recovery technologies are expected to improve the efficiency and quality of automotive recycling systems [9], [10].

2.4 Marine Engineering

Marine engineering is another important field in which recycled, recyclable, and waste-derived materials are being investigated for shipbuilding and marine structures. Their application can contribute to resource conservation, waste reduction, and more sustainable material use in marine industries.

In addition to materials containing recycled content, recyclable thermoplastic composites are important to marine circular-economy strategies because of their potential for recovery and reprocessing at the end of their service life. Polypropylene (PP), PLA, and polyamide are among the thermoplastic composites and are increasingly used because they can be mechanically recycled through grinding and remolding processes. According to the references, studies indicate that these thermoplastic composites can also help improve workplace safety in the manufacturing process by reducing exposure to liquid resins and the emissions they produce. Thermoplastic composites can be mechanically recycled through processes such as grinding and remolding. Their ability to be reheated, reshaped, repaired, and reprocessed after service makes them attractive for marine applications and may also reduce waste generated during manufacturing [11]–[13].

Recycled plastics and polymers are increasingly considered for marine applications such as decking, boat interiors, pipes, and floating structures. Recyclable polymers such as high-density polyethylene (HDPE) have also been investigated for marine components because of their potential for material recovery and reprocessing at the end of service life [11], [14].

In marine engineering, one of the widely used material types is composite materials, and they are commonly used due to their lightweight properties as well as their resistance to corrosion. Fiber-reinforced polymer composites improve structural performance while also reducing the weight of marine vessels. Recyclable resin systems and advanced composite-recycling technologies are also being investigated to improve the recovery of fibers and polymeric materials from end-of-life marine composite structures [11]–[14].

Bio-based and natural-fiber composites are also being investigated as sustainable alternatives for selected marine applications. Materials containing flax, hemp, and jute fibers have attracted attention because of their renewable origin and potential to reduce dependence on conventional petroleum-based materials. Studies on systems such as flax/PLA composites further demonstrate the potential for combining renewable materials with end-of-life recovery strategies. However, their long-term durability and performance in marine environments remain important considerations [11]–[15].

Recycled rubber materials are also used in different marine engineering applications. Recycled rubber is commonly used in dock fenders, vibration-damping systems, and marine flooring, according to the studies [16], [17]. The use of recycled rubber in these applications improves the durability and shock-absorbing capabilities of the materials, while also helping to reduce rubber waste and environmental pollution [16], [17].

The use of recycled materials provides several environmental benefits in marine engineering. According to the studies, the use of lightweight composite marine structures reduces fuel consumption and greenhouse gas emissions during the operation of marine vessels. Furthermore, the recycling of marine composite waste reduces the accumulation of waste in landfills and marine environmental damage. Additionally, studies in the references have discussed that the use of bio-composite materials helps to reduce the carbon emissions associated with the manufacturing of marine products. Finally, using recycled materials in marine industries helps to reduce the amount of energy required for manufacturing and the greenhouse gas emissions [11], [12], [14], [15].

In the marine industries, circular economy strategies have become very important. Circular economy approaches encourage recycling, remanufacturing, and reuse of marine engineering materials. Also, studies show that marine industries have started to pay attention to circular economy strategies to improve waste management and reuse materials. According to the studies, we can see that the main focus of sustainable marine structures is to reduce lifecycle environmental impacts through recyclable material selection and environmentally friendly manufacturing methods [12], [13], [15].

Despite these advantages, several challenges must be considered when recycled and recyclable materials are used in marine applications. Long-term durability and resistance to seawater are important performance requirements, while the complex composition of many fiber-reinforced composites makes end-of-life separation and recycling difficult. Further development of durable material systems and efficient composite-recycling technologies is therefore required to overcome these limitations [14], [15].

2.5 Electrical and Electronic Engineering

The increasing use and replacement of electrical and electronic equipment has resulted in growing quantities of electronic waste (e-waste). Effective management and recycling of this waste are important because discarded electronic equipment can contain both hazardous substances and valuable recoverable materials. Despite its advantages, fast-paced development results in a significant issue. Many electronics contain toxic components such as lead, mercury, cadmium, flame retardants, and may be extremely dangerous for the environment and human health [18]. Nonetheless, these items deemed worthless also contain valuable materials such as copper, aluminum, gold, silver, and rare earth elements. It is possible to reuse them after the successful process of recycling [18]. The majority of experts and researchers agree on the importance of effective recycling in reducing pollution and conserving natural resources [18]. These materials can be reused after successful recycling, dismantling, sorting, and then recovery [18]. Mechanical and physical methods are recommended due to their lower cost and reduced environmental risks compared to the options of discarding and incineration [18]. Proper recycling prevents a considerable part of waste from disposal and returns many valuable materials [18].

However, informal e-waste recycling remains an important environmental and occupational concern. Practices such as uncontrolled dismantling, open burning, and the use of chemical treatments can release hazardous substances into the surrounding environment and increase the risk of human exposure. Therefore, safer collection, separation, and material-recovery processes are required to reduce the environmental and health risks associated with improper e-waste handling [18], [19]. Recent research has increasingly focused on advanced recycling and recovery technologies that can improve material recovery while reducing environmental impacts [20]. Advances in recycling and material-recovery technologies have the potential to improve the efficiency of e-waste processing and increase the recovery of valuable materials while reducing environmental impacts [20]. Improved sorting, separation, and recovery processes can also support circular-economy strategies by returning recovered materials to productive use.

Overall, effective e-waste management requires appropriate recycling technologies, supporting infrastructure, regulatory frameworks, and responsible waste-management practices. When properly implemented, these measures can reduce environmental impacts, conserve valuable resources, and contribute to circular-economy objectives [18], [19], [20].

2.6 Aerospace Engineering

Composite materials have become increasingly important in modern engineering because of their high strength-to-weight ratio, corrosion resistance, fatigue resistance, durability, and design flexibility. In aerospace engineering, material selection for lightweight structures depends on several performance criteria, including strength-to-weight ratio, stiffness-to-weight ratio, fatigue resistance, impact resistance, density, thermal stability, and manufacturability [21]. Fiber-reinforced composites, particularly glass-fiber-reinforced polymers (GFRP) and carbon-fiber-reinforced polymers (CFRP), are widely used for lightweight structural applications because they can provide favorable mechanical performance at reduced structural weight [21], [22].

Compared with conventional metallic materials such as steel and aluminum, fiber-reinforced composites can provide advantages in specific applications, particularly where high strength-to-weight performance and corrosion resistance are required. However, their complex material structure can make end-of-life recovery and recycling more challenging [22], [23].

Despite these performance advantages, the increasing use of composite materials creates significant end-of-life management challenges. Unlike conventional metallic materials, fiber-reinforced composites can be difficult to separate and recover because the reinforcing fibers are embedded within a polymer matrix. Consequently, recycling technologies for GFRP and CFRP have become an important research area for improving material recovery and supporting more circular use of composites in aerospace engineering [23]–[25].

Another study examined the contribution of composite materials to waste management and recycling systems [24]. The recycling and reuse of aircraft materials and composite waste can reduce dependence on virgin raw materials, support material recovery, and contribute to more sustainable aerospace waste management [24], [25].

Recent developments in composite manufacturing have expanded the application of these materials across multiple engineering sectors [25]. Their high stiffness, thermal stability, and impact resistance make them suitable for both structural and non-structural components. Advances in composite materials have further supported their application in aerospace, automotive, and marine engineering [12], [14], [22], [25]. Several common themes emerge from the reviewed studies. Lightweight construction is a major advantage of composite materials and can improve engineering performance [22]–[25]. Fiber-reinforced composites can also provide advantages in mechanical performance and corrosion resistance for specific applications when compared with conventional metallic materials [22], [23]. However, their increasing use also creates challenges related to end-of-life management and recycling, making the development of effective composite-recycling strategies an important aspect of sustainable engineering [23]–[25].

3 METHODOLOGY

The methodology of this study is explained under the following subtopics.

3.1 Research Philosophy

The main objective of this research was to analyze existing knowledge on the use of recycled material applications in construction and other engineering fields. Since the main focus was on analyzing published literature rather than collecting numerical data, the interpretive view was considered more appropriate for this study. The method allowed researchers to estimate the recycled material impacts on sustainable development, environmental protection, resource conservation, and technological advancement.

3.2 Research Approach

An inductive research approach was used for this study. Common patterns, themes, advantages, challenges, and engineering applications were identified by reviewing the existing literature related to recycled materials. Rather than testing a predetermined hypothesis, conclusions were developed from observations and findings reported in the reviewed studies. This approach enabled a broader understanding of the role of recycled materials across the selected engineering fields.

3.3 Research Strategy

A structured literature review strategy was used for this study. Studies related to recycled materials were identified, selected, and reviewed according to their relevance to the research objectives. The review

focused on six engineering fields: construction, chemical, automotive, marine, electrical and electronic, and aerospace engineering. This approach enabled the applications, advantages, challenges, and sustainability aspects of recycled materials to be examined across the selected engineering fields.

3.4 Research Choice

This study followed a qualitative research methodology. A qualitative approach was chosen as the aim of this research to explore the applications, contribution to sustainability, environmental benefits, technological advancements, and limitations of recycled materials in various engineering fields. Detailed and analytical information obtained from secondary sources was used here rather than numerical analysis.

3.5 Time Horizon

A cross-sectional design was used for this study. Information was collected from published literature during the research period. Findings from published sources at different times were reviewed at one point in time.

3.6 Unit of Analysis

Published literature related to recycled materials and their engineering applications was used as the units of analysis in this study. Reliable academic sources such as journal articles, conference papers, review articles, and technical reports were considered to obtain the information required for the study. These sources provided a proper understanding of the use of recycled materials in various engineering fields.

3.7 Population and Sampling

The population of the study includes the academic publications available on the subjects of recycled materials, recycling technologies, waste management methods, and sustainable engineering practices.

Since the available literature was extensive, purposive selection was used to identify sources relevant to the objectives and scope of the review. Publications were selected according to the following inclusion criteria:

- Related to recycled materials or recycling technologies.
- Related to engineering applications.
- Contained information on environmental, economic, or technical aspects of recycling.
- Priority was given to peer-reviewed journal articles and reliable academic publications.
- Recent and relevant studies were selected whenever possible.

Based on these criteria, literature related to the fields of construction, chemical, automotive, marine, electrical, and aerospace engineering was selected and analyzed.

3.8 Data Collection and Analysis

The data collection and analysis process is described under the following subtopics.

3.8.1 Data Collection Method

This study was based entirely on secondary data collection methods. Information was collected from journal articles, conference papers, review articles, and scientific publications available online. The selected literature covered applications of recycled materials in six engineering fields.

Relevant information on recycled materials, recycling technologies, and engineering applications was collected and organized according to research objectives. The collected sources provided the basis for further analysis and comparison of recycled material applications across various engineering fields.

Table 1. Recycled materials and engineering applications reviewed

Engineering field	Recycled Materials Studied	Key Applications Reviewed
Construction Engineering	RCA, RAP, Fly Ash, Plastic waste, glass waste.	Concrete production, Road construction.
Chemical Engineering	Recycled plastics, Fly Ash, Slag.	Plastic manufacturing, Industrial manufacturing.
Automotive Engineering	Metals, Recycled plastics, Rubber.	Lightweight structures, Vehicle components.
Marine Engineering	Composite, Recycled polymers, Rubber.	Marine structure, Boat manufacturing.
Electrical Engineering	Electronic waste, Recovered metals.	Metal recovering, E-waste recycling.
Aerospace Engineering	CFRP, GFRP, and recycled composites.	Aircraft's structure, Lightweight components.

Table 1 above shows the engineering fields, recycled materials and their main applications reviewed in this study. According to reviewed studies, recycled materials are used for various purposes in various engineering fields. The table provides a complete summary which shows how engineers use recycled materials in their different work areas. The classification system enables researchers to organize their collected information for systematic analysis and comparison.

3.8.2 Data Analysis

The collected data was analyzed using Comparative thematic analysis. First, the literature was categorized by engineering field, and then similarities, differences and trends were identified under key themes.

Table 2. Comparative thematic analysis

Analysis theme	Main focus
Environmental Benefits	Waste reduction and pollution control, Conservation of natural resource.
Economic Benefits	Reduction of production costs, Improvement of resource efficiency.
Technological Development	Advancement of recycling technologies, Processing methods and innovations.
Sustainability Contribution	Support for circular economy and sustainable development
Challenges and Limitations	Identification of technical and operational barriers, Evaluation of quality and safety.

Table 2 above presents the main analytical themes used in this study and their areas of focus. The analysis was conducted under the themes of environmental and economic benefits, technological developments, contribution to sustainability, and challenges. The framework enabled researchers to identify similarities and differences between various engineering fields and evaluate the contribution of recycled materials to sustainable engineering practices.

3.9 Ethical Considerations

Ethical considerations were followed throughout the research process. As the study was based entirely on secondary data, there was no need for human participation or collection of personal information.

All information used in the study was obtained from publicly available academic sources, and proper citations and references were used to give due credit to the original authors.

3.10 Limitations of the Study

Since this study was based completely on secondary data, primary data collection methods were not used. Therefore, it was necessary to focus on previously published studies, scientific articles, and other academic sources to obtain the results of the research.

Furthermore, although the reviewed literature covered several engineering fields, some studies focused on specific materials or applications. Therefore, the review may not represent all recycled materials, recycling technologies, or potential engineering applications. Nevertheless, the study provides a broad overview of the use of recycled materials across the selected engineering fields and their contribution to sustainable engineering practices.

4 RESULTS AND DISCUSSION

This section presents the results and discussion through the following headings.

4.1 Discussion of Construction Engineering Applications

According to the reviewed literature, recycled materials have appeared as important options to traditional construction materials due to their environmental and engineering advantages. Bolden et al. have identified recycled concrete aggregate (RCA), recycled asphalt pavement (RAP), fly ash, waste glass, and recycled plastics as suitable materials for various construction applications [1]. Also, Akponovo and Onyebuchukwu reported that RCA can be successfully used in concrete production, highway construction, and drainage systems [2]. These studies show that acceptable engineering performance can be maintained while minimizing the use of natural aggregates.

RCA has been widely studied due to its potential use as a replacement for natural aggregates. Petkovic et al. found that the use of recycled aggregates can help reduce the environmental impact of road construction [3]. The studies conducted by Akponovo and Onyebuchukwu, together with Tam, have shown that the presence of old mortar and impurities can lead to increased water absorption and quality changes in recycled aggregates [2], [4]. The achievement of suitable performance requires organizations to follow proper processing systems together with quality control systems.

Fly ash has also been identified as an important, recycled material for sustainable construction. Akponovo and Onyebuchukwu reported that fly ash increases the workability of concrete, reduces water requirements and improves long-term durability [2]. Tam also examined the durability performance of concrete incorporating recycled aggregates [4]. The reviewed literature indicates that industrial by-products such as fly ash can be used to improve concrete performance while reducing the use of cement [2].

Recycled plastics and waste glass also have potential applications in the construction industry. Bolden et al. reported the use of recycled plastics in asphalt mixtures and pavement-related applications [1]. However, the use of waste-derived materials can also introduce technical challenges, and their effects on material performance must be carefully evaluated before implementation. These findings indicate that the environmental benefits of recycling should be considered together with engineering performance and material-quality requirements.

4.2 Discussion of Chemical Engineering Applications

Given these findings, the field of chemical engineering plays an important role in converting waste into valuable products using advanced recycling technologies. Waste plastics can be recycled through extrusion, pyrolysis, and chemical treatment to produce industrially useful materials [7], [8]. These technologies

reduce the increase of plastic waste while also providing alternative raw materials for manufacturing industries.

Landaverde Alvarado et al. have emphasized that sustainability-focused recycling projects improve resource efficiency and also promote innovative product development [26]. According to their findings, the field of chemical engineering directly contributes to sustainable industrial practices by converting waste streams into valuable products. Furthermore, the reviewed studies indicate that recycling technologies can support resource efficiency and reduce environmental impacts associated with plastic waste [7], [8], [26].

The reviewed literature further indicates that chemical engineering contributes to the processing and conversion of waste streams into materials suitable for further engineering applications. These processes can support waste reduction, resource recovery, and the production of secondary raw materials. Therefore, chemical engineering plays an important role in connecting waste management with the development of more sustainable materials and manufacturing systems [7], [8], [26].

4.3 Discussion of Automotive Engineering Applications

There has been an increase in the use of recycled materials by the automotive industry in relation to its sustainability practices. According to Heydari, recycled steel, aluminum, plastics, rubber, and glass have been widely used in vehicle production in order to minimize their effects on the environment and protect natural resources [9]. The recycling of metals has been important because it reduces the energy required for material processing.

Meshkat et al. examined the recovery and reuse of plastics from end-of-life vehicles (ELVs) [10]. Their study indicates that recycled automotive plastics can retain useful mechanical properties, including strength and stiffness, supporting their potential reuse in vehicle-related applications. These findings demonstrate how the recovery of materials from ELVs can contribute to circular-economy practices within the automotive sector [10].

The literature also highlights the environmental benefits associated with ELV recycling. Heydari reported that recycling vehicle components can reduce landfill disposal and greenhouse-gas emissions [9]. However, the reviewed studies also identify pollution control and material-quality management as important challenges in automotive recycling [9], [10]. Overall, ELV recycling offers sustainability benefits, but effective recovery and quality-control systems are necessary to maintain the performance and safety of recovered materials.

4.4 Discussion of Marine Engineering Applications

Research in marine engineering has shown that recyclable composite materials, recycled polymers, and bio-based materials are increasingly accepted in sustainable marine technologies. According to Elen et al., thermoplastic polymers are increasingly being used in marine applications because of their potential for recycling and end-of-life material recovery [11]. These characteristics make them more attractive choices than traditional thermoset composites, which are often difficult to recycle.

Elen et al. reviewed polymer composites used in marine renewable-energy structures and discussed their potential for end-of-life recovery, reuse, and recycling [11]. Similarly, Crupi et al. highlighted that bio-based composites are eco-friendly because their manufacturing produces fewer CO2 emissions than petroleum-based composites [14].

Natural-fiber composites have also gained attention in marine engineering. Curto et al. examined bio-based composites for marine applications and highlighted long-term durability and resistance to marine

environmental conditions as important considerations [15]. The reviewed literature also indicates that recycling fiber-reinforced marine composites remains challenging because of their complex material structure [12]. Therefore, further research is required to improve composite-recycling technologies and the durability of sustainable material systems in marine environments.

4.5 Discussion of Electrical and Electronic Engineering Applications

The increasing use and disposal of electronic devices have made e-waste management an important engineering and environmental concern. Gramatyka et al. reported that valuable metals, including copper, aluminum, gold, and silver, can be recovered from discarded electronic equipment [18]. The recovery of these materials can support resource conservation and reduce dependence on primary raw material extraction.

Gramatyka et al. further stressed that the inclusion of hazardous materials such as lead, mercury, and cadmium in improper e–waste disposal and informal recycling practices can result in significant environmental and health issues [18]. These results emphasize how crucial it is to set up efficient recycling programs and legal frameworks.

Beyond e-waste recovery, recyclable material design is another circular-economy approach relevant to electrical and electronic engineering. Najafi et al. demonstrated the development of recyclable and electrically conductive biocomposite materials for robotic grippers and touch sensors [27]. Such developments illustrate the potential for material design and recyclability to contribute to circular-economy strategies.

4.6 Discussion of Aerospace Engineering Applications

Advanced composite materials are widely used in the aerospace industry because of their high strength-to-weight ratio and corrosion resistance. Previous studies have discussed the application of glass-fiber-reinforced polymers (GFRP) and carbon-fiber-reinforced polymers (CFRP) in lightweight engineering applications [21], [22]. Habib et al. further examined the role of composite materials and recycling approaches in supporting more sustainable engineering practices [24].

Despite their engineering advantages, composite materials present considerable end-of-life recycling challenges. Vijay et al. discussed the challenges associated with composite waste management and material recovery [25]. Similarly, Asmatulu et al. examined recycling approaches for advanced composite materials and highlighted the importance of improving material recovery from composite waste [23].

Collectively, the reviewed studies indicate that improving composite recycling and material-recovery methods is important for enhancing sustainability in aerospace engineering. Habib et al. highlighted the potential of recycling and reuse strategies to reduce composite waste and support more circular approaches to material use [24].

4.7 Overall Discussion

The reviewed studies demonstrate that the role of recycled and recyclable materials differs across the six engineering fields. In construction engineering, the primary emphasis is on replacing conventional raw materials with recycled aggregates and industrial by-products [1]–[3]. Chemical engineering contributes mainly through recycling and conversion technologies that transform waste streams into useful secondary materials [7], [8]. Automotive engineering emphasizes the recovery and reintegration of materials from end-of-life vehicles, supporting circular material flows [9], [10]. Marine engineering extends this approach to recyclable composites, recycled polymers, and selected bio-based material systems [11]–[15]. In

electrical and electronic engineering, the principal focus is the recovery of valuable materials from e-waste [18], [19], [20], whereas aerospace engineering presents a different challenge because the increasing use of advanced composites requires effective end-of-life recycling and material-recovery strategies [22]–[25].

Despite differences among the engineering fields, several common challenges emerge from the reviewed literature, including variability in recovered-material quality, environmental risks associated with improper recycling, durability requirements, and difficulties in processing complex material systems. Addressing these challenges requires improvements in material separation, recovery, processing, and quality control. Future research should therefore focus on developing efficient recycling technologies while ensuring that recovered materials satisfy the technical and durability requirements of their intended engineering applications.

5 CONCLUSION

This review examined the application of recycled materials across six selected engineering fields: construction, chemical, automotive, marine, electrical and electronic, and aerospace engineering. The reviewed literature demonstrates that recycled and waste-derived materials can contribute to sustainable engineering by reducing waste generation, conserving natural resources, supporting material recovery, and reducing dependence on virgin raw materials.

The role of recycled materials differs across the selected engineering fields. Construction engineering primarily applies recycled aggregates and industrial by-products as alternatives to conventional materials, while chemical engineering contributes through technologies that convert waste streams into useful secondary materials. Automotive engineering emphasizes the recovery and reintegration of materials from end-of-life vehicles, whereas marine engineering includes recycled polymers, recyclable composites, and selected bio-based material systems. Electrical and electronic engineering focuses largely on recovering valuable materials from e-waste, while aerospace engineering faces particular challenges in the end-of-life recovery and recycling of advanced composite materials.

Despite these benefits, several challenges remain, including variability in recovered-material quality, durability requirements, complex recycling processes, and the need for effective quality-control and regulatory frameworks. Addressing these challenges is important for the reliable and sustainable application of recycled materials in engineering.

Overall, the reviewed literature demonstrates that recycled materials can contribute to more sustainable engineering practices across the selected fields. Further progress depends on improving recycling and material-recovery technologies, maintaining the engineering performance of recovered materials, and addressing field-specific technical and implementation challenges. Continued research in these areas can support more efficient use of resources and the broader application of circular-economy principles in engineering.

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