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Polymeric materials and their applications

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Abstract

Materials obtained from nature are divided into two groups: natural and artificial. Materials fall into four main categories: metals, ceramics, polymers, and composites. Glass is a solid material that is transparent, usually rigid, fragile, and has an inorganic amorphous structure that allows the preservation of liquids. Ceramics, on the other hand, are solid materials containing metal and non-metal inorganic compounds with ionic or covalent bonds. Nontechnical ceramics fall into three general groups: cement and concrete, fired clay, minerals, and stone. Fibers and particles are utilized as strengthening constituents in different types of composite materials. Hybrids can be used as different types of composite materials and thermal insulation parts. Hybrid materials are divided into four groups: composites, foams, honeycombs, and natural materials. Composites and foams can be made from metallic, ceramic, or polymer-based matrices. Metals and their alloys are materials connected by metallic bonds. Metals are divided into two groups: ferrous and non-ferrous. A polymer is a substance comprised of enormous molecules. Polymers have larger molecular masses than small molecule compounds. Polymers are materials connected by covalent bonds and dominant van der Waals bonds. Polymeric materials are divided into two groups: elastomers and plastics. Plastics (polymers) are divided into two main parts: thermoplastics and thermosets. Thermoplastics can be reused when heated due to their weak bonds, meaning they are suitable for recycling. A thermoset is a thermosetting polymer and is a material attained by permanently hardening the resin. Industrial usage areas of polymers include textiles, electronic goods, the automotive industry, healthcare, building materials, and food. In this study, polymeric materials were defined, then classified and their usage areas were criticized.

Keywords: Polymers, Applications, Ceramics, Glasses, Metals, Composites

1. Introduction

Materials science is an interdisciplinary branch of science that studies the structure and properties of substances and includes the production or synthesis of new materials [1]. The intelligent beginning of materials science staunches from the Illumination Age, while investigators started using logical discerning from engineering, physics, and chemistry to recognize antique explanations in metallurgy and mineral science. Materials science even includes portions of chemistry, physics, and production. Therefore, it has been considered a subfield of these connected grounds by academic institutions. Commencing in the 1940s, materials science became more broadly identified as a definite and conspicuous discipline of science and manufacturing, and foremost technical universities everywhere the world invented specialized disciplines for their search. Materials researchers highlight recognizing in what way the past of a material affects its form and therefore the material's possessions and accomplishments. Recognizing process-structure-property interaction is labeled the material concept. This concept is utilized to enhance comprehension in various study fields, including biomaterials, metallurgy, and nanotechnology.

Materials science is an essential component of forensic engineering and damage examination—the investigation of substances, artifacts, constitutes, or elements that decline to role as proposed, triggering individual wound or property impairment. Such research, for example, is key to insight into the triggers of several flight crashes and events. Materials science is one of the oldest fields of functional science and engineering. In the antiquity of individual advancement, numerous periods have regularly been defined looking back allowing the advancement of man's capacity to work with a new style of substances. Expressions for instance the Stone Age, the Bronze Age, and the Iron Age are good cases of this. In fact, material science, which emerged from ceramic production and its derived metallurgy, is one of the oldest forms of applied sciences and engineering. Modern materials science developed immediately from metallurgy, which developed from mining, ceramics, and the utilization of fire. The advance in sympathetic materials happened in the late 19th century, while American researcher Gibbs J. W. discovered that thermodynamic possessions associated with atomic structures in different phases were linked to the physical possessions of a material. Significant aspects of contemporary materials science are a result of the space race. Recognizing and technique of metal alloys, flint, and carbon materials employed in the building of spacecraft that enable space investigation. Materials science has influenced and is influenced by the advancement of innovative knowledge such as biomaterials and plastic semiconductors.

Before the 1960s, several materials science sections were called metallurgy sections, revealing the importance given to metals in the 19th and 20th centuries. The increase of materials science in the United States was facilitated by the "Advanced Research Projects Agency" in the 1960s, which financed many university workshops to enlarge the national program of crucial investigation and education in materials science. The subject has subsequently expanded to incorporate all classes of materials, including ceramics, polymers, semiconductors, implants, and biological materials.

Many valuable components of advanced materials science stemmed from the space race. Especially, the sympathetic and engineering of metallic alloys, ceramics, and other materials have been utilized in the building of spacecraft, spacesuits, and the like, and the new knowledge gained has led to the growth of a diversity of customer and industrial applications. Materials science has laid the physical institutions of 21st-century development, being a fundamental part of the entirety from fiber optic cables to tennis shoes, from solar cells to sailboats. Materials science is central to the search to find technological explanations for maintainable growth in the face of environmental mortification and the constant accumulation of glasshouse gases by reason of the coloring of carbon-based fuels [1].

The aim of this study is to make a critical study on polymeric materials and their applications. Here, the materials are first divided into five groups: ceramics, fibers, composites, metals, and polymers. Then, these five groups of materials are classified as polymeric materials, elastomers, and plastics, and these polymeric materials were subdivided into thermoplastics and thermosets. Again, a critical comparison was made by considering the physical, mechanical, thermal, and electrical possessions of these items. Finally, the wide usage areas of polymeric materials are discussed and examined.

2. Material types

Materials, all kinds of substances used naturally or artificially to make usable objects, are called "materials".

Materials are a matter or combination of constituents that make up an item. Substances can be pure or impure, living, or non-living matter. Materials can be categorized according to their physical and chemical belongings or their geological source or biological behavior. Materials science is the branch of science that studies the structure and properties of materials. In nature, oil, natural gas, etc. There is an infinite amount of material that can form different deposits of rocks, soils, or minerals. Materials are divided into two groups: natural and artificial, which are obtained from nature and people can use them as they wish. Traditionally, materials are divided into three main categories: metals, ceramics, and polymers. Apart from this, there are also composite materials in which at least two of these three main materials are used together [1].

2.1. Ceramics and glasses

Glass is a solid substance with an inorganic amorphous structure that is transparent, mostly hard, fragile, and admits the conservation of liquids. Glass has been utilized as both a building material and decorative items since ancient times. Currently, it even has an ample scope of uses, from easy utensils to interaction and space technologies. For example, it has prevalent useful, technical, and attractive uses in window glass, glass packaging, mirrors, lamps, tableware, and optics.

The best-known and traditionally ancient, produced kinds of glass are "silicate glasses" founded on the chemical compound silica, which is the principal component of sand. Including approximately 70% silica, soda-lime glass versions for approximately 90% of glass produced. Certain items, for instance, gulping glasses and glasses, are so generally made from silicate-based glass that they are referred to austerely by the moniker of the items.

Glass is a fluid material formed by dissolving unexpectedly iced alkali and alkaline earth metal oxides and selected other metal oxides, and its main material (SiO2) is silicon. The glass hardens although conserving its amorphous formation. Owing to instant chilling through fabrication, an amorphous construction is created rather than a crystal structure. This structure creates glass with its strength and transparency properties. It is occasionally described as a liquid since it does not show the crystallization possessions observed in solids. This naming is mainly due to its amorphous structure.

Ceramic is a solid material containing metal and non-metal inorganic compounds with ionic or covalent bonds. Common examples of use are earthenware (non-vitreous pottery, glazed or unglazed), porcelain, and brick. The first ceramics made by people were ceramic vessels made of clay that was fire-hardened and sintered, either spontaneously or mixed with further items such as silica. The ceramics were then glazed and fired to become smooth, create painted surfaces, and reduce permeability via vitreous use. Ceramics now include a wide variety of ceramic arts, as well as domestic, industrial, and construction products. In the 20th century, new ceramic substances were exploited for utilization in improved ceramic engineering, for instance, semiconductors.

2.1.1. Glasses

Glass objects are partitioned into eleven groups: alumina silicate, barium silicate, borosilicate, glass ceramics, high-performance glass, leaded glass, alkali glass, silica, soda-lime, soda-zinc glass, and soda-zirconia glass. The physical assets of these glass items are displayed in Table 1.

Table 1. Physical possessions of glass materials [2]

Glasses	Physical properties [density (kg/m^3)]	Typical uses
Alumina silicate	$2.49x10^3 – 2.54x10^3$	Airplane windows, frangible containers, lamp envelopes, top-of-stove uses, ignition tubes
Barium silicate	$2.73x10^3 – 2.78x10^3$	Substrate
Borosilicate	$2.45x10^3 – 2.50x10^3$	Ovenware, lab ware, piping, sealed beam headlights, optical filters

Glasses	Physical properties [density (kg/m^3)]	Typical uses
Glass-ceramics	$2.51 \times 10^3 – 2.56 \times 10^3$	Precision dielectric components, insulators, high vacuum components
High-performance glass	$2.35 \times 10^3 – 2.45 \times 10^3$	Safety windows, floors, staircases
Lead glass	$5.36 \times 10^3 – 5.47 \times 10^3$	Solder sealing
Alkali glass	$2.65 \times 10^3 – 2.70 \times 10^3$	Color TV panel
Silica	$2.15 \times 10^3 – 2.20 \times 10^3$	High temperature
Soda-lime	$2.47 \times 10^3 – 2.52 \times 10^3$	Electronic and lamp tubing
Soda-zinc glass	$2.62 \times 10^3 – 2.67 \times 10^3$	Lamp bulbs
Soda-zirconia glass	$2.59 \times 10^3 – 2.64 \times 10^3$	Laboratory ware

2.1.2. Non-technical ceramics

Non-technical ceramics are divided into three general groups: cement and concrete, fired clays, minerals, and stone. Table 2 shows the physical properties of these non-technical ceramic materials.

Table 2. Physical properties of non-technical ceramic materials [2]

Non-technical ceramics	Physical properties [density (kg/m^3)]	Typical uses
Cement	$1.90 \times 10^3 – 2.30 \times 10^3$	Used to make concrete for general civil engineering construction. As mortars to cement brick, as rendering on floors and walls.
Concrete	400 – 900	Fixing blocs, insulation
Ceramic tile	$2.05 \times 10^3 – 2.40 \times 10^3$	interior floors; walls in bathrooms and other 'wet' rooms; pools; laboratories; exterior building enclosures and roofs, paving, and other weather-resistant surface applications.
Porcelain	$2.26 \times 10^3 – 2.42 \times 10^3$	Structural power insulators, low tension insulators
Spinel	$3.57 \times 10^3 – 3.72 \times 10^3$	Refractory
Granite	$2.63 \times 10^3 – 3.20 \times 10^3$	Measuring tables; building facing; work surfaces; curbstones; and sculpture
Limestone	$2.55 \times 10^3 – 2.60 \times 10^3$	Building, facing, sculpture
Marble	$2.72 \times 10^3 – 2.85 \times 10^3$	Building, facing, work surfaces, decoration, sculpture
Sandstone	$2.24 \times 10^3 – 2.65 \times 10^3$	Florentine architecture in the 13th to 19th century

2.1.3. Technical ceramics

Technical ceramics are divided into fourteen groups: alumina, aluminum nitride, beryllia, bio-glass ceramic, boron carbide, calcium phosphate, carbon and graphite, magnesia, mullite, silicon carbide, silicon nitride, steatite, tungsten carbide, and zirconia. Table 3 exhibits the physical possessions of these technical ceramic objects.

Table 3. Physical properties of technical ceramic materials [2]

Technical ceramics	Physical properties [density (kg/m^3)]	Typical uses
Alumina	$3.34x10^3 – 3.47x10^3$	High-frequency precision coil formers; Small, low-power fuse bodies; Electrical insulators; Wear parts; Injector cones; Aerial strain insulators
Aluminum nitride	$3.27x10^3 – 3.33x10^3$	Substrates for microcircuits; Chip carriers; Heat sinks
Beryllia	$2.83x10^3 – 2.88x10^3$	Chip carriers; Heat sinks; Substrates; Power semiconductor housings; Missile nose cones; Microwave components; Thermocouple insulators; Nuclear reactor moderator rods; Crucibles; Microwave windows
Bio-glass ceramic	$3.05x10^3 – 3.09x10^3$	Medicine
Boron carbide	$2.48x10^3 – 2.53x10^3$	Slurry nozzles; Lightweight body armor
Calcium phosphate	$3.05x10^3 – 3.15x10^3$	Medicine, Bone
Carbon	$1.30x10^3 – 1.80x10^3$	Molds for metal casting
Graphite	$1.50x10^3 – 1.54x10^3$	Electrodes for metal production
Magnesia	$3.54x10^3 – 3.58x10^3$	Refractories, corrosion-resistant parts
Mullite	$2.70x10^3 – 3.00x10^3$	Ball mills; pump parts; spark plugs; crucibles; refractories
Silicon carbide	$3.11x10^3 – 3.18x10^3$	Mechanical seal faces; Bearings; Turbocharger bearings; Gas turbine rotors; High-temperature devices, Laboratory test equipment; Hydraulic plungers
Silicon nitride	$3.11x10^3 – 3.28x10^3$	Thermocouple sheaths; Stoppers and seats; Crucibles; Injection bushes; Riser tubes; Weld location pins; Pump components; Welding, brazing, and soldering components
Steatite	$2.57x10^3 – 2.62x10^3$	Radiofrequency applications - valve bases, HF coil formers, brushes, tubes
Tungsten carbide	$1.53x10^3 – 1.59x10^3$	Cutting tools; abrasives; Cermet
Zirconia	$6.03x10^3 – 6.16x10^3$	Wear-resistant parts; corrosion-resistant parts; structural applications; engine and turbine parts

2.2. Fibers and particulates

Fibers and particulates are divided into five groups: ceramic particulates, ceramic and glass fibers, natural fibers, metal, and polymer fibers. These kinds of fibers and particulates are used as reinforced materials in different types of composite materials.

2.3. Hybrids: composites, foams, honeycombs, natural materials

Hybrid materials are divided into four groups: composites, foams, honeycombs, and natural materials. These kinds of hybrids can be used as different types of composite materials and for the sake of heat insulation parts. Composites and foams can be made of metallic, ceramic, or polymer-based matrices.

2.4. Metals and alloys

Metals and alloys are divided into seven groups: ferrous (steels, cast iron, etc.), magnetic (AlNiCo, SmCo, etc.), non-ferrous (Al, Cu, Cr, etc.), other metals (Ca, Sb, V, etc.), precious metal alloys (Au, Pt, etc.), rare earth metals (Ce, Nd, Sc, etc.), and refractory alloys (Mo, Nb, Ta, W, etc.).

2.5. Polymers: plastics, elastomers

A polymer is a matter composed of very large macromolecules collected from numerous replicating subunits. Because of their wide range of possessions [3], polymers, equally synthetic and natural, play a fundamental and abundant function in daily life [4]. Polymers scope from acquainted synthetic plastics, for example, polystyrene to natural biopolymers for instance DNA and proteins that are essential for biological construction and tasks. Together synthetic and natural polymers are constructed through the polymerization of numerous petite molecules recognized as monomers. They have larger molecular mass than small-molecule combinations, producing distinctive physical possessions such as hardness, high elasticity, viscoelasticity, and a leaning to form amorphous and semi-crystalline constitutes instead of crystalline ones.

3. Polymeric materials and applications

The phrase "polymer" descends from the Greek words (meaning "many") and *meros*, meaning "part", and its structure consists of large numbers of repeating molecules [3]. The modern thought of polymers as covalently linked macromolecular structures was projected in 1920 by H. Staudinger [4]. Polymers are examined in the disciplines of polymer science, biophysics, and materials science and engineering. Traditionally, inventions resulting from the bonding of recurring units by covalent chemical bonds have been the attention of polymer science. An important promising field now aims at supramolecular polymers formed by non-covalent bonds. Polymeric materials are divided into two groups: elastomers and plastics.

3.1. Elastomers

An elastomer is a polymer that contains viscosity and elasticity in its structure [5]. The difference between elastomers and thermoplastics in their molecular structure stems from the fact that the molecular chains consisting of organic compound-forming elements such as C, H, S, F, O, or Cl are connected by cross-links in certain regions containing unsaturated C, even to a small extent. These features give them the ability to change strain at a high rate.

During mechanical stress of elastomers, cross-links begin to open, allowing the chains to stack in the direction of strain, for this reason, they have the capacity to extend up to 10 times [5]. When the strain is removed, the shape change disappears, and they return to their previous length. One point that should be noted is that the elasticity modules of these chains, which are arranged in the direction of strain, increase in direct proportion.

As for plastic deformation, since they are not connected by weak, secondary van der Waals bonds like thermoplastics, chain slips do not occur at high temperatures, and viscous behavior is not observed. One of the areas where elastomers are most used industrially is tire production [1]. Elastomers are usually thermosetting but can also be thermoplastic.

3.1.1. Thermoplastic elastomers (TPE)

Thermoplastic elastomers are divided into ten groups: MPR (melt-processable rubber), POE/POP (polyolefin elastomer/plastomer), PVC-elastomer (polyvinyl chloride), TPA/PEBA (thermoplastic polyamide elastomer/polyether block amide), TPC/TEEE/COPE (thermoplastic copolyetherester elastomer), TPO (thermoplastic polyolefin ester), TPS (styrene block copolymers), TPU (thermoplastic polyurethane elastomer), TPV (thermoplastic vulcanizate). The physical possession of some thermoplastic elastomers is shown in Table 4.

Table 4. Physical possession of some thermoplastic elastomers [2]

Thermoplastic elastomers	Physical properties [density (kg/m^3)]	Typical uses
MPR (Shore A 60)	$1.11x10^3 – 1.17x10^3$	Cable Jacketing; Fabrics; Gaskets; Handles; Hose; Parts, Engineering; Seals; Sheet; Tubing; Weatherstripping; Wire Jacketing; Appliances; Automotive Interior Parts
POE/POP (Shore A 65)	864 – 872	Plastics modification
PVC-elastomer (Shore A 35)	$1.08x10^3 – 1.12x10^3$	Plastics modification
TPA/PEBA (Shore D25)	$999 – 1.01x10^3$	Conveyor belts; Silent gears; Shock-absorber parts; breathable films; soles with studs as well as shells for mountain boots; Roofing film; Packaging for fresh produce; catheters, surgical gowns, inflators
TPC/TEEE/COPE (Shore D40)	$1.14x10^3 – 1.18x10^3$	Conveyor belts; Silent gears; Shock-absorber parts; breathable films; soles with studs as well as shells for mountain boots; Roofing film; Packaging for fresh produce; catheters, surgical gowns, inflators
TPO (PP+EPDM) Shore A55	856 – 930	Gaskets; Seals
TPS (SBS) Shore A50	$936 – 1.02x10^3$	Footwear; Gaskets; Medical Applications; Seals; Sporting Goods; Toys; Tubing; Grips, Flexible; Food Service Applications; Closures; Film
TPU (Polyester) Shore A70	$1.15x10^3 – 1.19x10^3$	Adhesives; Automotive Applications; Parts, Thick-walled; Profiles; Tubing; General Purpose; Compounding; Industrial Applications; Textile Applications; Belts/Belt Repair; Gaskets; Footwear; Sporting Goods
TPV (PP+NBR) Shore A75	$1.00x10^3 – 1.02x10^3$	Substitution of rubber (thermoset elastomers) in applications requiring oil resistance

3.1.2. Thermoset elastomers (rubber)

Thermoset elastomers are divided into fifteen groups: ACM (Acrylic rubber), BR (Butadiene rubber), CM (Chlorinated polyethylene), ECO ((Epichlorohydrin rubber), CR (Chloroprene), EPDM (Ethylene propylene diem rubber), EVM (Ethylene vinyl acetate rubber), FEPM (Fluoro elastomer), IIR (Halobutyl rubber), NBR

(Nitrile rubber), NR (Nature rubber), PUR (Polyurethane rubber), SBR (Styrene butadiene rubber), SI (Silicone elastomer), TM (Polysulfide rubber). The physical assets of some thermoset elastomers are exhibited in Table 5.

Table 5. Physical possession of some thermoset elastomers [2]

Thermoset elastomers	Physical properties [density (kg/m^3)]	Typical uses
ACM (Acrylic rubber)	$1.09 \times 10^3 – 1.10 \times 10^3$	Automotive accounts for 80% of applications: engine gaskets and seals, O-rings, oil hoses, and transmission seals. Used as binders for propellants and explosives due to favorable C, H, O ratio (~30% oxygen)
BR (Butadiene rubber)	910 – 940	Mainly used in blends with natural rubber and SBR, notably in car tires where it reduces heat buildup and wear. Also, seals, electrical insulation, tubing, rubber lining pipes, and pumps, plastic impact modification
CM (Chlorinated polyethylene)	910 – 940	“
ECO (Epichlorohydrin rubber)	910 – 940	“
CR (Chloroprene)	$1.23 \times 10^3 – 1.30 \times 10^3$	Wire & cable coating, hose, automotive timing belts, wet suit sponge, soles and heels, rubber coating for fabrics, roof coatings. Also, adhesives -- pre-eminent among elastomeric adhesives due to a combination of polarity and strength
EPDM (Ethylene propylene diem rubber)	860 – 880	Roofing, seals, gaskets, hose (garden hose, steam pressure hose), cable insulation, polypropylene modification
EVM (Ethylene vinyl acetate rubber)	$1.04 \times 10^3 – 1.08 \times 10^3$	Automotive seals and hoses; flame retardant foams and cable sheathing; wear and weather-resistant floor coverings; translucent cover of 'Powermoon HeliMax' lighting
FEPM (Fluoro elastomer)	$1.55 \times 10^3 – 1.60 \times 10^3$	Oil seals, O-rings, seals, wire & cable jacketing. Typical industries: oil and gas, food processing, nuclear and conventional power generation, chemical processing, automotive, heavy-duty diesel, electronics, machinery, fluid controls, steam generation. Special niche in sour

Thermoset elastomers	Physical properties [density (kg/m^3)]	Typical uses
		oil and gas production applications
IIR (Halobutyl rubber)	910 – 950	Inner tubes of pneumatic tires, vacuum and high-pressure applications, seals, belts, anti-vibration mounts, electrical insulation, tubing, rubber lining pipes and pumps, chewing gum, pharmaceutical closures (halobutyl)
NBR (Nitrile rubber)	950 – 1.02x10^3	Automotive, seals, fuel and oil hose, gloves
NR (Nature rubber)	930 – 970	Car tires, seals, belts, anti-vibration mounts, electrical insulation, tubing, gloves, condoms, rubber lining for pipes and pumps, adhesives, carpeting, textiles, rubber bands
PUR (Polyurethane rubber)	1.15x10^3 – 1.19x10^3	Cushioning, packaging, shoe soles, tires, wheels, fuel hoses, gears, bearings, wheels
SBR (Styrene butadiene rubber)	940 – 961	Car and truck tires, belt, hose, footwear
SI (Silicone elastomer)	1.05x10^3 – 1.07x10^3	Medical: seals, syringe plungers, breast nipple protectors, catheters, sterilization mats, O-Rings for dialysers, baby bottle parts
TM (Polysulfide rubber)	1.25x10^3 – 1.34x10^3	Permanent putties for fuel tank sealants, fuel hose liners, and gaskets; lacquer/inking/paint rollers; gas bladders; flexible molding making

3.2. Plastics

Plastic is called monomers, it is collected from rudiments for example carbon (C), hydrogen (H), oxygen (O), and nitrogen (N). It is the designation assumed for materials attained by infringing the bonds in modest molecular groups and transforming them into a long-chain construction named polymer. The expression plastic is obtained from the Greek words (*plastikos*) denotation "able to be shaped or molded" and (*plastos*) proposing "molded". For example, Ethylene is a monomer. Polyethylene created from this monomer is a polymer. It is one of the most used plastics. As can be understood from the definition, plastics are not found in nature, they are obtained by human intervention in the elements in nature. It is obtained by reacting to monomers using a catalyst under a certain temperature and pressure. When plastic is first produced, it can be in powder, resin, or granule form. Plastics are divided into two main parts including thermoplastics and thermosets. We can count more than 50 plastics among thermoplastics [ABS, ANMA, ASA, CA, CAB, CAP, CN, COC, COP, EC, ECTFE, EMA, ETFE, EVA, EVOH, FEP, LCP, MABS, PA, PAI, PB, PBI, PBT, PC, PCL, PCT, PCTFE, PE, PEEK, PEI, PEN, PET, PETG, PFA, PGA, PHA, PI, PLA, PMMA, PMP, POM, PP, PPC, PPE, PPS, PS, PSU, PTFE, PTT,

PVC, PVDC, PVDF, SAN, SB, SMA, SMMA, SRP, TPS, TPU]). There are also about 10 plastics among thermosets [DAP, EP, MF, PF, PI, PUR, UF, UP, VE].

3.2.1. Thermoplastics

Thermoplastic is a polymer substance that develops mold at a definite temperature and solidifies after chilling [1][2]. Most thermoplastics have extreme molecular mass. Polymer chains combine by intermolecular influences, which promptly decline with increasing temperature and form a viscid fluid. In this case, thermoplastics can be restructured and are often employed to make parts through a variety of polymer-giving out methods for instance injection and compression molding, rolling, and extrusion [4][5]. Thermoplastics contrast with thermosetting polymers, or "thermosets," which form permanent chemical bonds through the preserving procedure. Thermosets do not dissolve when warmed, but generally decay and do not restore after chilling. The physical possessions of some thermoplastic objects are illustrated in Table 6.

Table 6. The physical possessions of some thermoplastic elastomers [2]

Thermoplastic elastomers	Physical properties [density (kg/m^3)]	Typical uses
ABS (Acrylonitrile Butadiene Styrene)	$1.02 \times 10^3 – 1.08 \times 10^3$	Safety helmets; automotive instrument panels; pipe fittings; home-security devices; communications equipment; business machines; plumbing hardware; automobile grilles; wheel covers; mirror housings; refrigerator liners; weather seals; glass beading; refrigerator breaker strips; conduit; pipe for drain-waste-vent (DWV) systems
ASA (Acrylate styrene acrylonitrile)	$1.05 \times 10^3 – 1.06 \times 10^3$	Outdoor signs; Exterior panels; Garden furniture
EMA (Ethylene methyl acrylate copolymer)	927 – 940	Film, disposable gloves, wound care, tubing
EVA (Ethylene Vinyl Acetate)	930 – 940	Stretch film for wrapping, shoe soles, medical equipment, flexible toys, tubing
PA (Polyamide)	$1.07 \times 10^3 – 1.10 \times 10^3$	Gears; cams; rollers; bearings; nuts and bolts; power tool housing; electrical connectors; combs; coil formers; fuel tanks for cars; kitchen utensils
PBT (Polybutylene Terephthalate)	$1.30 \times 10^3 – 1.38 \times 10^3$	Electrical connectors; gears; heat-resistant panels in domestic and electrical goods; under-bonnet and exterior parts for cars; light fittings and reflectors; switches; bobbins; brush holders; integrated circuit carriers
PC (Polycarbonate)	$1.14 \times 10^3 – 1.18 \times 10^3$	Safety shields and goggles; lenses; instrument casings; lighting fittings; safety helmets; electrical switchgear; twin-walled sheets for glazing; kitchenware and tableware; microwave cookware, medical (sterilizable) components

Thermoplastic elastomers	Physical properties [density (kg/m^3)]	Typical uses
PE (Polyethylene)	920 - 1.24x10^3	Cable covering; shrink-wrap film; heat-shrinkable tubing; pipe for domestic heating systems; rotationally molded tanks
PEEK (Polyetheretherketone)	1.30x10^3 – 1.32x10^3	Wire covering; injection molded engineering products; film for flexible PCB; resin in fiber prepregs; aerospace applications; radiation environments; medical devices
PET (Polyethylene Terephthalate)	1.29x10^3 – 1.39x10^3	Blow molded bottles; packaging film; film; photographic and X-ray film; audio/visual tapes; industrial strapping; capacitor film; drawing office transparencies; fibers
PLA (Polylactic acid)	1.24x10^3 – 1.27x10^3	biodegradable packing and disposables, food packaging, plastic bags, plant pots, diapers, bottles, cold drink cups, electronic cases, home textiles, clothing, medical implants, homeware
PMMA (Polymethylmethacrylate)	1.16x10^3 – 1.22x10^3	Light fittings; Display signs; Domestic baths; Packaging; Safety spectacles; Tool handles; Motorcycle windscreens; Baby incubators
POM (Polyoxymethylene)	1.39x10^3 – 1.41x10^3	Bearings; Gears; Electrical kettles; Snap-fit components; Chemical pumps; Bathroom scales; Pulley wheels; Domestic appliance housings; Shower heads; Fuel expansion tanks; Toys
PP (Polypropylene)	982 - 1.16x10^3	Furniture; Housings; Electrical/Electronic Applications; Buckets; bowls; general mechanical parts; bottle crates; toys; medical components; washing machine drums; pipes; battery cases; bumpers; films for packaging
PPS (Polyphenylene Sulfide)	1.34x10^3 – 1.36x10^3	Electrical components; chemical pumps; under-bonnet components; coatings for chemical and/or abrasion resistance

Thermoplastic elastomers	Physical properties [density (kg/m^3)]	Typical uses
PS (Polystyrene)	$1.04 \times 10^3 - 1.05 \times 10^3$	Toys; light diffusers; beakers; cutlery; general household appliances; video/audio cassette cases; electronic housings; refrigerator liners
PTFE (Polytetrafluoroethylene)	$2.14 \times 10^3 - 2.20 \times 10^3$	Bearings; chemical vessel linings; pipe and valve linings; pumps; impellors; pipes; gaskets; diaphragms; piston rings; coating for non-stick applications
PVC (Poly Vinyl Chloride)	$1.45 \times 10^3 - 1.56 \times 10^3$	Hot water piping; fibers; lacquers
SAN (Styrene Acrylonitrile)	$1.06 \times 10^3 - 1.08 \times 10^3$	Cups; toothbrush handles; trays; containers; covers; cassette cases; battery cases; dials; knobs; switches; lenses
TPU (Polyurethane)	$1.12 \times 10^3 - 1.24 \times 10^3$	Automotive, appliance, footwear, construction, furniture, and recreation industry

3.2.2. Thermosets

In materials science, a thermosetting polymer, repeatedly identified as a thermoset, is a polymer attained by permanently strengthening a soft solid or viscid fluid resin [1, 2]. Curative is initiated by heat or appropriate radiation and may be assisted by high pressure or combination with a catalyst. Heat is certainly not joined outwardly and is usually produced by the rejoinder of the resin with a catalyst or hardener. Curative solutions in chemical consequences initiate large cross-linking among polymer chains to form a soluble and unsolvable polymer association. The commencing objects for creation thermosets are generally pliable or liquid before preserving and are repeatedly devised to be formed into the closing model. It can also be utilized as an adhesive. Unlike thermoplastic polymers, which are generally fabricated and allocated in the method of capsules and manipulated into concluding creation form by fading, pressing, or injection molding, a thermoset cannot vanish to reshape once it has hardened. The physical possessions of some thermosets are exhibited in Table 7.

Table 7. The physical possessions of some thermoset materials [2]

Thermoset elastomers	Physical properties [density (kg/m^3)]	Typical uses
PADC (Poly allyl di-glycol carbonate)	$1.30 \times 10^3 - 1.40 \times 10^3$	Spectacle lenses
DAP (Diallyl phthalate)	$1.65 \times 10^3 - 1.85 \times 10^3$	Electrical connectors; relays; switches; potentiometers; contact bases; commutators
EP (Epoxy)	$1.11 \times 10^3 - 1.40 \times 10^3$	Potting; Casting; Encapsulating; Impregnating
MF (Melamine formaldehyde)	$1.60 \times 10^3 - 2.00 \times 10^3$	Industrial laminating; Decorative laminating; Adhesives; Protective coatings; Textile treatment; Paper manufacture
PF (Phenol formaldehyde)	$1.24 \times 10^3 - 1.32 \times 10^3$	Electrical parts - sockets, switches, connectors, general industrial, water-lubricated bearings, relays, pump impellers, microwave cookware, handles, bottles tops, coatings, adhesives, bearings

Thermoset elastomers	Physical properties [density (kg/m^3)]	Typical uses
PI (Polyimide)	$1.50x10^3 – 1.80x10^3$	Bearings; valve seats; piston rings; gears, bearings, electrical insulation; engine parts; printed circuit boards, film (Kapton) for capacitors; coatings for electrical components
PUR (Polyurethane)	$1.04x10^3 – 1.06x10^3$	Cushioning; packaging; insulation; foam-in-place buoyancy; shoe soles; car bumpers; tires; wheels; gears; fuel hose; housings; panels; bearings; gears
UF (Urea formaldehyde)	$1.47x10^3 – 1.52x10^3$	Industrial laminating; Decorative laminating; Adhesives; Protective coatings; Textile treatment; Paper manufacture
UP (Polyester)	$1.01x10^3 – 1.20x10^3$	Linings-Pipes, Vessels
VE (Vinyl ester)	$1.01x10^3 – 1.08x10^3$	Flooring maintenance, plumbing parts, tanks, automotive parts, exhaust duct systems, piping, coating applications, filaments, equipment requiring maximum resistance to bleach chemicals, marine applications, wind turbine blades, formulation of adhesives and coatings, manhole covers

3.3. Polymer applications

Polymers have a wide variety of uses. Among the industrial usage areas, we can count the following areas: textile, electronic goods, automotive industry, healthcare, building materials, food and beverage industry, and sports equipment [6-10]. Brief explanations about these usage areas will be given below.

3.3.1. Textile

Among the most used clothing items, we see jeans and t-shirts made of cotton. Cotton thread is a natural polymer produced from cellulose. In addition to cotton, wool, and silk are also natural polymers. In recent years, in addition to the use of these natural threads in the textile field, it is possible to see synthetic threads produced from various polymers in various textile fields. Artificial polymer-based synthetic threads; by adding various additives, these polymers can be used as high-tech textile materials where fireproofing, waterproofing, pollution resistance, and elasticity are required.

3.3.2. Electronics

Perhaps the most common use of materials made of polymers is electronic devices. Although polymers with thermoplastic properties are generally preferred in the products used in this field, it is very imperative to select the right polymer type depending on the exact usage area. Choosing the right polymer material directly affects the reliability and quality of the product. Polyethylene (PE) or polyvinyl chloride (PVC) is used in cable production. If the cable to be used needs to be resistant to high temperatures, it is preferred to be produced from poly (vinylidene fluoride) (PVDF) polymer. CDs, CD covers, tape recorders and stereo frames are also made from common commercial plastics called polycarbonate, polystyrene or ABS. CD players and computer motherboards are also made from polymers and epoxies.

3.3.3. Automotive industry

The automotive industry is one of the areas where plastic materials are used most frequently. Lighter and cheaper automotive production is increasingly achieved by using plastic instead of metal parts wherever possible. Due to the lightness, fuel consumption in the car becomes more economical. Rubber is the leading polymer used in all vehicles. Rubber, the basic material of car tires, is a polymer that can be produced both synthetically and naturally. Another car part where rubber (polyisoprene) is used is windshield wipers. ABS polymer, which is resistant to impact, is used in the fabrication of fragments for example bumpers and fenders. Vehicle headlights are made of polycarbonate, a transparent polymer. The plastic mats we use in the vehicle are generally made of nylon or polyurethane.

3.3.4. Health

The use of plastic is becoming widespread in the medical equipment industry. Syringes, gloves, bandages, and goggles are just a few. The disposable feature of plastics not only reduces the risk of infection for the user; In terms of production and cost, it almost eliminates the sterilization step. Gloves used in laboratory and surgical environments are generally made of latex. Latex is a rubber-based synthetic polymer. Disposable syringes are among the medical supplies and are generally made of plastic or glass called polyethylene. Thanks to its resistance to chemicals, it is also used in laboratories conducting scientific research. Disposable laboratory syringes can also be made from polystyrene. Some polymers used in biomedical areas are shown in Figure 1.

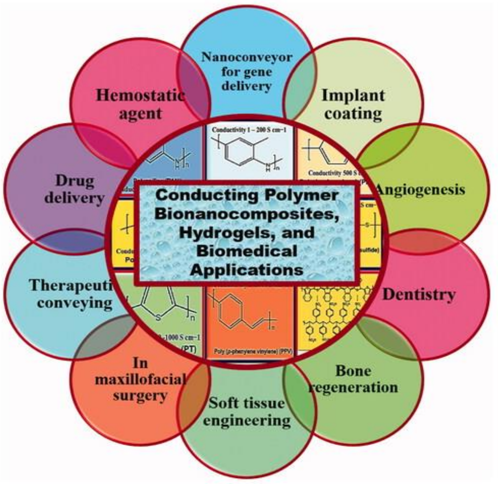

Figure 1. Some polymers are used in biomedical areas

3.3.5. Construction materials

Plastic materials or plastic-based composite materials can be seen in every field of building materials, from infrastructure products to home decoration products. The most commonly used infrastructure product is poly(vinyl chloride) (PVC) based plastic water pipes. These pipes can be controlled with polypropylene valves and water purification elements can be installed with PVC-based parts. Additionally, PVC polymer can also be used as roofing and floor covering.

3.3.6. Food beverage industry

Although it has been written about the harms of plastic to human health in recent years, we still see plastic materials in our kitchens. For example, plastic trays are usually made of polyethylene. The glasses we use to drink water from dispensers are made of polypropylene or polystyrene. The transparent plastics we use to wrap food are produced from a polymer called poly(vinylidene chloride) (PVDC), whose trade name is Saran®. Plastics produced in the packaging of food and beverages have created a separate and very large plastic sub-industry. Plastic bottles that hold beverages such as water and carbonated juices are generally made of poly (ethylene terephthalate) (PET). Industrial research is still being carried out on these issues and efforts are being made to increase the shelf life of stored food or beverages. Even though the problem of gas permeability of polymers has not been fully solved, today we can also see wine and beer bottles made of plastic.

3.3.7. Sports items

Polymers are widely used in the production of sports goods. Its usage area is not limited to just clothing; Polymers are also used in durable and lightweight sports equipment. The most used polymers include polyurethane, nylon, acrylic, epoxy, PVC, polypropylene, and polyester. Nylon and polyurethane are the most common plastics used especially in sports shoes. SBS or Polyurethane polymers are generally used in shoe soles. Shoelaces are also made of nylon or cotton. Rain boots, which have become very fashionable in recent years, are generally made of Polyisoprene. Some sports items made from polymeric materials are illustrated in Figure 2.

Figure 2. Some sports items are made from polymeric materials

4. Sustainability

The concept of sustainability is an approach that aims to use resources effectively and preserve natural balance to meet the needs of current and future generations [11]. In this part, sustainability will be discussed in nine subsections as follows.

4.1. Recyclability of materials

From an environmental perspective, the ideal material should be fully recyclable or fully biodegradable. The recyclability of a material means that a part produced from this material can be reprocessed after completing the material cycle, can re-enter the material cycle, and can be reused as another part, and this process is repeated indefinitely.

Only thermoplastic materials can be recycled from polymers. Thermoset materials cannot be recycled. The reason for this is that thermoplastic materials have a soft chain structure. For this reason, their rigidity is low, and they are used repeatedly by heating. However, since thermoset materials are cross-linked, their rigidity is high. Therefore, carbonization occurs when they are heated. Therefore, thermosets cannot be recycled and cause environmental pollution problems. In summary, Thermoplastics are recyclable and, as is known, recycling is an important point compatible with sustainability because it reduces waste and supports the circular economy [12].

4.2. Sustainable material choices

Complete biodegradability means that the material breaks down and returns to almost the same form as it was originally processed by the environment (natural chemicals, microorganisms, oxygen, heat, sunlight, etc.). Engineering materials can be found in a variety of levels of recyclability and biodegradability.

Most metal alloys (e.g. Fe, Cu) corrode to some extent and are biodegradable. However, some metals (e.g. Hg, Pb) are toxic and pose a health risk when buried in the ground. In addition, most metal alloys are recyclable; however, it may not make economic sense to recycle all metal alloys. The quality of recycled alloys also tends to decline with each cycle.

The most consumed ceramic material by the public is glass. Glass is not affected by chemicals and does not dissolve, so it is not biodegradable. A significant portion of municipal landfills contain glass waste, which cannot be disposed of by incineration. In addition, since the raw materials (sand, soda ash, and limestone) are cheap and widely available, there is no economic impetus for recycling glass.

Composites are inherently difficult to recycle. This is primarily due to their multiphase nature. The two or more materials/phases that make up the composite are mixed in a very finely divided manner, making the process of separating them difficult to recycle. However, some methods have been developed that can be successfully applied on an acceptable scale for polymer matrix composites. Since only thermoplastics can be recycled among polymer materials, it is expected that more thermoplastics and fewer thermosets will be used in industry in the next 25-30 years as environmental awareness increases.

In summary, you can investigate how the choice of materials (especially polymers and composites) can affect environmental sustainability, for example, the use of biodegradable materials or those sourced responsibly.

Polymer materials are divided into three categories: thermoplastics, thermosets, and elastomers. Of these, only thermoplastic materials can be recycled. In other words, they can be used repeatedly for heating. They can cause environmental pollution. However, thermosets and elastomers cannot be recycled because they are cross-linked. They can cause environmental pollution. Because thermosets take 500-1000 years to dissolve in nature and cause environmental pollution.

Composite materials are preferred in many engineering applications due to their durability and superior strength. Composite materials must be evaluated with an appropriate waste disposal or recycling method when their lifespan ends. Many waste management and environmental legislation will require engineering materials such as automobiles, wind turbines, or aviation to be recovered and recycled with an appropriate method after their economic lifespan has ended.

Although many mechanical, thermal, and chemical recycling technologies have been developed, they are not yet fully commercialized methods. Extensive research and development studies are being carried out to efficiently recycle composite materials and develop recycling technologies. Such studies will contribute to sustainable development in the composite industry [12].

4.3. Impact of materials on sustainability

Material sustainability refers to the production, use, and disposal of a given material in an environmentally, economically, and socially sustainable manner. This concept includes several important elements to consider when selecting materials:

a. Resource use: Sustainable materials require the efficient use of natural resources. This means opting for renewable resources and using recyclable materials.

b. Environmental impact: It is important to minimize the negative impacts of the material on the environment during production, use, and waste management. This includes elements such as reducing greenhouse gas emissions, and water and energy savings.

c. Economic sustainability: Procuring and processing the material cost-effectively is important for economic sustainability. It should also be considered that sustainable materials are designed to save money and reduce costs in the long term.

d. Social sustainability: The human health and social impacts of materials are also important. The use of safe and healthy materials can have positive effects on society.

In short, sustainability of materials refers to adopting an environmentally friendly and economically efficient approach. This is an important responsibility for both producers and consumers.

Energy efficiency is very important in sustainability. Energy efficiency is the goal of reducing the amount of energy required to provide products and services. For example, insulating a house allows a building to use less heating and cooling energy to achieve and maintain a comfortable temperature. Using LED lighting, fluorescent lighting, or skylights for natural light reduces the amount of energy required to achieve the same level of illumination compared to using traditional incandescent bulbs. Improvements in energy efficiency are often achieved by adopting a more efficient technology or production process, or by implementing widely accepted methods to reduce energy losses.

There are many motivations for improving energy efficiency. Reducing energy use reduces energy costs, and if the energy savings offset the additional costs of implementing an energy-efficient technology, they can save consumers financial costs. Reducing energy use is also seen as a solution to the problem of reducing greenhouse gas emissions. According to the International Energy Agency, improved energy efficiency in buildings, industrial processes, and transportation could reduce world energy needs by one-third by 2050 and help control global greenhouse gas emissions.

In addition, materials, toxic substances, and waste used in sustainability are also extremely important. Because as the world population increases, the volume and variety of materials used have also increased, and transportation distances have increased. These may include raw minerals, synthetic chemicals (including hazardous substances), products, food, living organisms, and waste. As long as economic growth rates and natural resource consumption rates remain proportional to each other, it is expected that humanity will use 140 billion tons of minerals, ores, fossil fuels, and biomass annually by 2050 (three times today's figures). People in developed countries use a total of 16 tons per person per year from these four basic resources, and in some developed countries this figure can reach 40 tons and above, which is far beyond the possibility of sustainability.

Sustainable use of materials aims to transform the linear processing path of materials into a circular material flow aimed at reuse as much as possible, such as recycling and reusing waste in nature. This approach is supported at all levels, especially in individual countries and the global economy, by the conscious use of products and the increasing use of material movement analyses. The use of sustainable biomaterials from renewable sources that can be recycled is preferred over non-renewable materials from a material life cycle perspective.

The construction and automotive industries have an important place in sustainability. Sustainable construction focuses on the use of renewable and recyclable materials in construction to reduce energy consumption and waste. A construction carried out with sustainable construction techniques stands out by approaching the minimum impact on the environment.

There are two main reasons why sustainable construction has become a trend – climate crisis and energy costs. Today, we can say that the construction sector accounts for 36% of the world's energy use. In addition to these data, the construction sector also accounts for 40% of global CO2 emissions. Sustainable construction focuses on the use of renewable and recyclable materials in construction to reduce energy consumption and waste. A construction carried out with sustainable construction techniques stands out with its effect on the environment approaching the minimum.

Of course, it is not limited to this. Building project design that will ensure that a completed building has a minimum environmental impact is also an important part of the sustainable construction concept. We can even say that the materials used should be selected in a way that will benefit the environment. Solar panels, green concrete, energy-saving roofs or insulation techniques are good examples of this.

The construction sector does not only contribute to carbon emissions. The boundaries of the concrete piles that are expanding day by day also threaten wildlife. We can collect the effects of the sustainable construction concept under three headings: environmental, economic, and social benefits.

According to the Environmental Protection Agency (EPA), buildings are responsible for 30% of all greenhouse gas emissions in the USA. Today, large companies are constantly adapting and supporting green initiatives in the USA and the rest of the world. Property owners and large businesses prefer to impose sustainability, which is positive for society and businesses, on their processes.

According to the US Green Building Council (USGBC), the green building sector generates over $134.3 billion in labor income. This data shows that sustainable construction, in the American economy, provides employment opportunities to meet the increasing demand for construction workers. Sustainability also involves using environmentally friendly construction materials while maintaining quality and structural integrity. Recycling and reusing materials also helps reduce the money spent on materials.

- The quality of the environment we live in affects us all physically, mentally, and emotionally. It is a proven fact that sustainable architecture improves the quality of life of its residents and increases the overall quality of life.
- Businesses that adopt sustainable construction contribute to the creation of a more sustainable planet that affects future generations. The global social impact of sustainable construction is more important than the benefits it provides to businesses and local communities. Because it sets an example for both the construction sector and other sectors.
- The market for sustainable buildings is growing steadily with increasing public awareness. As a result, the size of the green construction sector doubles every three years.

Secondly, let's look at sustainability and environmental approaches in the automotive sector.

The automotive industry is looking for innovative solutions to improve environmental problems and adopt sustainable practices. In this direction, it is pioneering a major transformation in terms of sustainability and environmental approaches.

The automotive sector, which is an important part of the global economy, has begun to take on more and more responsibility in terms of increasing environmental sustainability. Traditional automobile production processes leave a serious carbon footprint with high energy use, metals, plastics, toxins, and manpower. However, the automotive industry is looking for innovative solutions to solve these problems and adopting sustainable practices. Issues such as electric motors, lightweight construction materials, and reducing CO2 emissions have become an important part of sustainability in the automotive sector. Luxury brands are trying to spread sustainability effects such as the use of natural fibers by keeping ecological and aesthetic standards high in interior design. In addition, automotive manufacturers are contributing to sustainable change by reviewing every stage of their business processes, from vehicle design to production and transportation processes, vehicle operation, service delivery, and the end of the product life cycle. The automotive sector is one of the fundamental components of the global economy and sustainability is vital for the future of this industry. Sustainability affects the automotive industry at every stage with its economic, ecological, and social aspects. Today, automotive companies are developing new strategies to reduce environmental impacts, increase resource efficiency, and fulfill their social responsibilities. Sustainability manifests itself in three main areas: design and engineering, production processes, and vehicle operation. For example, the use of lightweight materials and waste management are important steps to increase sustainability in production processes. In addition, innovations such as electric vehicles and hybrid technologies play a significant role in the industry’s efforts to reduce its environmental impact. Customer expectations and government policies are also driving automotive companies to adopt more sustainable practices. Consumers are demanding more efficient vehicles that are less harmful to the environment. These demands are encouraging the automotive industry to develop innovative solutions that lead to sustainability. Sustainability also provides a competitive advantage in the automotive sector. Companies that adopt sustainable practices both gain customer trust and reduce operational costs. In addition, sustainability-focused innovations enable the emergence of new business models and revenue streams. As a result, sustainability in the automotive sector is not only an environmental imperative but also an economic opportunity. By adopting sustainability strategies, companies can protect our planet and ensure long-term success. The automotive sector’s progress towards a sustainable future will be possible through the joint efforts of all stakeholders.

It can be said that the automotive industry has undergone a major transformation in terms of sustainability and environmental approaches. Sustainability is not only limited to environmental impacts in the sector but also includes social and economic dimensions and the sector's contribution to social sustainability becomes evident in areas such as employee health and safety, education, and development opportunities. In addition, it is seen that steps such as the transition to a circular economy and waste management play an important role in reducing the environmental impacts of the sector. In the future, the automotive sector is expected to take sustainability and environmental approaches even further, while the increase in the production and use of electric vehicles, the development of alternative fuel technologies, and investments in smart transportation systems are among the basic elements that will enable the sector to move towards an environmentally friendly future. This transformation is also supported by the increase in environmental awareness of consumers and the increasing demand for green technologies. The future of sustainability and environmental approaches in the automotive sector is aimed to be shaped by global and local policies as well as technological innovations and to contribute to sustainable economic growth in the sector [13].

4.4. Incorporation of sustainable metrics

The assessment of the environmental impact of different materials is of great importance for sustainability. The criteria used in this assessment reveal the impact that the material has on the environment throughout its life cycle. The most considered criteria include carbon footprint, energy consumption during production, and recyclability.

Carbon footprint: The carbon footprint refers to the total amount of greenhouse gases released into the atmosphere during the production, use, and disposal of a material. This value is usually measured in CO_2 equivalent per kilogram. The measurement of the carbon footprint includes the extraction of the raw material, production processes, transportation, use, and final disposal stages. Materials with a low carbon footprint are a priority, especially in the fight against climate change. For example, recycled steel has a much lower carbon footprint than virgin steel because less energy is used during the reprocessing of the raw material.

Energy consumption: Another important measure of the environmental impact of materials is the energy used in the production process. This energy can come from fossil fuels or renewable sources. Energy consumption from fossil fuels negatively impacts the environment by increasing carbon emissions, while the use of renewable energy can reduce the environmental footprint. For example, aluminum production is a process with high energy consumption; however, if this energy is provided from renewable sources, the environmental impact is reduced. Therefore, when evaluating the environmental impact of a material, the energy source and amount at the production stage are of great importance.

Recyclability: Recyclability refers to the potential of a material to be converted into a reusable resource at the end of its life. Recyclable materials minimize environmental impact by reducing the need for raw materials and contributing to the circular economy. For example, materials such as glass, metal, and paper can be recycled repeatedly, while the recycling rates of plastics vary depending on the material type and sometimes cannot be recycled for economic or technical reasons. Therefore, recyclability is a critical factor in terms of sustainability in material selection.

In conclusion, when evaluating the environmental impact of materials, criteria such as carbon footprint, energy consumption, and recyclability should be considered. Since each material has different environmental impacts, these factors ensure a balanced decision when making a choice [14].

4.5. Sustainable alternatives

The importance of sustainable material alternatives is increasingly emphasized in terms of reducing environmental impact and preserving natural resources. Sustainable options are available in every material category (metals, ceramics, polymers) and these options offer advantages over traditional materials in terms of criteria such as carbon footprint, energy consumption, and recyclability. Here are examples of sustainable materials or applications for each category and their benefits:

Metals (Recycled aluminum and steel): Recycled aluminum and steel are strong alternatives for sustainability in metal production. Recycled aluminum consumes approximately 95% less energy than virgin aluminum production. Similarly, steel is a metal that is highly suitable for recycling, with approximately 30% of steel production made from recycled materials. Recycling offers benefits such as low energy consumption, waste reduction, and circular economy.

Ceramics (Ceramics made with natural and local raw materials): The production of traditional ceramics requires high temperatures, which increases energy consumption. However, ceramics made from local and natural raw materials that can be fired at low temperatures offer a sustainable alternative. Some types, especially bio-ceramics, are a sustainable option developed for use in biomedical applications. Using ceramics fired at low temperatures reduces energy consumption, local raw materials, and transportation, reducing carbon footprint. In addition, the durability of ceramics provides long-lasting use and reduces the need for renewal, thus reducing their impact on the environment in the long term.

Polymers (Biodegradable polymers): Biodegradable polymers offer a sustainable alternative to plastic use, especially in food packaging, agriculture, and disposable products. These polymers can decompose rapidly in nature depending on environmental conditions. For example, polymers such as polylactic acid (PLA) and polyhydroxyalkanoates (PHA) are obtained from plant sources and are biodegradable. Thanks to biodegradable polymers, plastic waste is reduced, production is made from renewable resources, and food safety and hygiene are ensured.

The use of sustainable alternative materials not only reduces the environmental footprint, but also supports the achievement of broader sustainability goals such as resource efficiency, long-lasting use, and circular economy. In addition, the development and use of sustainable materials is an important step in building an environmentally conscious society. These alternatives provide sustainable material options for both industrial applications and consumer products, contributing to leaving a more livable world for future generations [15].

4.6. Lifecycle analysis

Life cycle analysis (LCA) is an approach that comprehensively examines the environmental impacts of a material throughout its life cycle, from “cradle to grave.” This analysis method evaluates all stages from raw material extraction to production, distribution, use, and final disposal. LCA helps quantify the environmental impacts of materials and encourages sustainability-oriented material choices. Let’s examine how LCA can be useful for the metal, ceramic, and polymer materials discussed. LCA has five stages: raw material extraction, production process, distribution and transportation, life cycle, and disposal and recycling. In the first stage of LCA, the energy consumed, and waste generated during the process of obtaining the material from natural resources are evaluated. Then, LCA analyzes the energy consumption, greenhouse gas emissions, and other environmental impacts during the production process. The carbon footprint of the materials during transportation is also taken into account within the scope of LCA. The selection of materials from local sources can reduce energy consumption and emissions from transportation. The durability of a material determines whether it needs to be renewed or replaced throughout its lifespan. Long-lasting and durable materials can be more sustainable in terms of LCA. The final stage of LCA covers how the material will be disposed of or recycled at the end of its lifespan.

The benefits of life cycle analysis include:

Comprehensive Assessment of Environmental Impact: LCA analyzes the environmental impacts of the material throughout its life cycle, considering impacts throughout the entire process, not just at the production or use stage. This helps us understand that environmental impacts can be seen throughout the entire life cycle, not just at a specific stage.

Guidance in Selecting Sustainable Materials: LCA facilitates the selection of the most suitable materials in terms of sustainability by comparing the environmental impacts of various materials. For example, choosing biodegradable polymers instead of traditional plastic packaging results in lower environmental impact.

Reduction of Resource Use: LCA encourages the selection of resource-efficient materials by considering the consumption of energy and raw materials during the production process. For example, materials such as recycled steel or aluminum require fewer natural resources than virgin raw materials.

Supporting the Circular Economy: LCA supports the circular economy by highlighting options such as recycling or reuse at the end of the product life cycle. This reduces environmental impact by preventing waste of materials.

The applicability of LCA for these materials can be summarized as follows:

Metals: For metals such as recycled aluminum and steel, LCA demonstrates the positive effects of recycling on energy and carbon emissions and reduces metal waste. In this way, metal recycling rates can be increased and a more sustainable material cycle can be created.

Ceramics: For ceramics made from natural raw materials, LCA contributes to the development of firing methods with low energy consumption by evaluating the energy and raw materials used in the production process. It also reduces emissions from transportation by encouraging the use of local resources.

Polymers: LCA of biodegradable polymers shows that they have a much lower carbon footprint and waste rate than traditional plastics. LCA can help these polymers find a wider use in sustainable applications.

As a result, LCA provides a comprehensive assessment for each type of material to ensure environmental sustainability. LCA encourages conscious material choices by considering environmental impacts at all stages. This increases resource efficiency, reduces carbon footprint, and supports a circular economy. This analysis method enables material choices to be made from an environmentally friendly perspective for a sustainable future [16].

4.7. Industry trends

Today, many sectors are undergoing a transformation in line with the need for sustainability and reducing environmental impact. Sustainability trends that stand out in sectors such as circular economy, eco-design, and increasing regulatory pressures are enabling businesses to turn to an environmentally friendly and long-term value creation-focused approach. Let's examine how these sustainability-focused trends provide a change for companies and consumers by detailing the impact of each of these trends on the sector.

Transition to Circular Economy Principles: The circular economy moves away from the traditional "take, make, throw away" model and allows materials to be reintroduced into the cycle in order to extend the life of products, reduce waste, and encourage reuse. This model minimizes waste production, reduces the need for raw materials, and increases energy efficiency in production processes. In particular, the electronics, construction, and textile sectors are taking important steps towards reducing their waste by adopting circular economy practices.

Some of the prominent practices are given below:

- Product Return and Reuse: This practice, which has become widespread, especially in the technology and fashion sectors, allows consumers to return or exchange used products and thus enables the reuse of products.
- Use of Recycled Materials: In line with circular economy principles, the rate of depletion of natural resources is reduced by manufacturing with recycled raw materials such as plastic, metal, and textile.
- Modular Design: In sectors such as electronic devices and furniture, modular design allows products to be more easily repaired or parts to be replaced, thus extending the life of the product.

The benefits of circular economy applications can be summarized as follows: it optimizes resource consumption while reducing waste, provides long-term cost savings, and also helps brands develop an environmentally friendly image.

Eco-Design Approach: Eco-design aims to design products using more sustainable materials, increasing energy efficiency, and according to recyclability principles in order to reduce environmental impacts throughout their entire life cycle. In this approach, all processes from raw materials to disposal are carefully considered to minimize the environmental damage of products. Eco-design applications are becoming increasingly widespread, especially in the packaging, construction materials, and furniture sectors.

Some of the prominent applications are briefly mentioned below:

- Minimum Material Use: Resource saving is achieved by avoiding unnecessary material use in the packaging or design of products.
- Preference for Renewable Resources: In eco-design, materials produced from renewable resources such as bioplastics, recycled metal, or natural wood are used.
- Ease of Recycling and Disassembly: In order to facilitate the recycling of products, designs are made in a way that they can be easily disassembled. This application is rapidly becoming widespread, especially in the furniture and electronics sectors.

Eco-design reduces carbon footprint by reducing resource consumption and provides a positive contribution to the brand in the eyes of consumers by offering environmentally friendly product options.

Regulatory Pressures and Environmentally Focused Policies: Regulatory pressures are increasing in many countries of the world to comply with environmental protection policies and sustainability goals. Regulations such as the European Union's Green Deal, China's 2060 carbon neutrality target, and various state laws in the USA are providing a sustainability-focused transformation with tightened environmental regulations, especially in sectors with high carbon emissions.

The prominent practices are summarized in three items below:

- Greenhouse Gas Emission Restrictions: Specific targets are set to reduce carbon emissions, especially in sectors such as energy, heavy industry, and transportation, and companies are switching to green energy to achieve these targets.
- Waste Management and Recycling Obligations: In many countries, companies are held responsible for recycling product packaging. New regulations have come into force, especially to reduce plastic packaging waste.
- Green Finance and Incentives: Sustainable investments such as environmentally friendly technologies and renewable energy use are encouraged, and companies benefit from financial support for low-carbon solutions.

Regulatory pressures encourage companies to raise environmental sustainability standards and develop climate-friendly strategies. This contributes to reducing negative impacts on the environment and preserving natural resources in the long term.

The impact of sustainability trends by sector can be briefly expressed as follows for the electronics, textile, and automotive sectors:

- Electronics and Technology Sector: In the electronics sector, the production of modular and repairable devices stands out as an important step towards reducing resource consumption and e-waste.
- Textile Sector: The use of recycled fabrics, natural dyes, and renewable fibers strengthens the sustainable fashion trend in the textile sector; and encourages the slow fashion concept instead of fast fashion.
- Automotive Sector: Electric vehicles stand out in line with the targets of reducing carbon footprint, while at the same time increasing energy efficiency by using recyclable and lightweight materials.

As a result, these sustainability-focused sector trends not only reduce environmental impact; they also contribute to long-term cost savings, innovation, and competitive advantage in the market. Thanks to circular economy principles, eco-design, and regulatory pressures, companies develop more future-sensitive, environmentally friendly, and value-oriented business models; and invest in a sustainable future [17].

4.8. Case studies

Industries that have succeeded in sustainable material selection aim to reduce their environmental impact by adopting circular economy principles and eco-design principles. Here are a few case studies from industries that have successfully implemented sustainable practices using metal, ceramic, and polymer materials:

Metals Industry (Apple and the use of recycled aluminum): Apple is making efforts to reduce its environmental impact by using recycled aluminum in its devices. For example, the use of 100% recycled aluminum in its MacBook and iPad models has helped Apple significantly reduce its carbon footprint.

The use of recycled aluminum in the material selection has been favored, which has resulted in less energy used and reduced carbon emissions.

As a result, this strategy has been well-received by environmentally conscious consumers and has strengthened Apple’s brand image as a sustainable technology leader. It has also created a low-cost and environmentally friendly production model.

Ceramics Industry (Interface and low-temperature ceramic tiles): Commercial carpet and flooring manufacturer Interface supports sustainable design strategies with low-temperature ceramic tiles.

Interface has reduced energy consumption by developing a low-temperature firing method, reduced carbon emissions by using local materials, and Interface’s ceramic tiles have a long service life thanks to their durability, which reduces waste in the long term.

As a result, Interface has reduced energy costs and contributed to the circular economy thanks to its ceramic tiles produced at low temperatures. The company has increased customer loyalty by reducing its environmental impact and has become a sustainability-focused leader in the sector.

Polymer Sector (Danone and biodegradable polymer packaging): Danone, a leading company in the food and beverage sector, aims to reduce its environmental impact by using biodegradable polymers in its product packaging. Danone has turned to the use of biopolymers (e.g. polylactic acid - PLA) to reduce pollution caused by plastic packaging.

The carbon footprint has been significantly reduced thanks to the use of biodegradable PLA polymers, environmentally friendly biopolymers, and the use of biopolymers in packaging.

As a result, Danone has contributed to its sustainability goals by using environmentally friendly packaging. This strategy has helped consumers trust Danone as an environmentally conscious brand and facilitated its compliance with environmental regulations.

Construction Sector (LafargeHolcim and low-carbon cement): LafargeHolcim, one of the leading companies in the construction sector, is leading the way in reducing the sector’s carbon footprint by focusing on developing low-carbon cement. Since cement production is an energy-intensive process, LafargeHolcim aims to minimize environmental impact by using recycled construction waste.

Materials obtained by recycling construction waste are reused in cement production. Low-carbon cement production processes have reduced energy consumption and reduced carbon emissions by up to 25% compared to traditional methods.

As a result, LafargeHolcim has increased the demand for environmentally friendly construction materials in the sector by offering sustainable construction solutions. The company has complied with environmental regulations and become a leader in sustainability in the sector thanks to low-carbon cement.

In summary, these case studies demonstrate how choosing sustainable materials can provide tangible benefits in the industry. Companies are reducing their environmental impact with sustainable options such as recycled and biodegradable materials, while also achieving gains in areas such as economic efficiency and brand value.

These examples clearly demonstrate how industries are contributing to a sustainable future and how environmentally responsible practices provide a strategic advantage in business [18].

4.9. Research and innovation

Innovations in materials science have the potential to align with sustainable development goals. Research into environmentally friendly, durable, and recyclable materials is leading to significant advances in sustainability. For example, innovations such as biodegradable materials, manufacturing processes that reduce carbon footprints, and designs that increase energy efficiency not only reduce negative impacts on the environment but also enable more efficient use of natural resources.

Such work contributes to balancing economic growth, environmental protection, and social progress, which are fundamental principles of sustainable development. In addition, new discoveries in materials science can help develop more efficient solutions for green energy technologies (e.g., materials used in solar cells or wind turbines) and waste management.

With the success of these and similar studies, energy savings will be achieved, environmental pollution will be prevented, and people will be able to live a more comfortable life [19, 20].

5. Conclusions

We can divide materials into five groups: ceramics, fibers, composites, metals, and polymers. In addition, it is possible to examine polymeric materials in two subgroups: recyclable thermoplastics and non-recyclable thermosets. It is seen that the physical, mechanical, thermal, and electrical possessions of materials in different groups are different from each other. As a result of the study titled “polymeric materials and their applications”, the following results were obtained:

1. Materials obtained from nature are divided into two groups: natural and artificial. Traditionally, materials are divided into three main categories: metals, ceramics, and polymers. Apart from this, we can also include the group of composite materials in which at least two different materials from these three main groups are used together.
2. Glass is a solid material that is transparent, largely hard, fragile, and has an inorganic amorphous structure that allows the preservation of liquids. Glass is a fluid material whose main material ($SiO2$) is silicon, founded by the suspension of suddenly chilled alkali and alkaline earth metal oxides and some supplementary metal oxides. The glass solidifies while sustaining its amorphous structure. Because of instant chilling through production, an amorphous construction is formed rather than a crystal structure. This building creates glass its strength and transparency properties. Ceramics, on the other hand, are solid materials containing metal and non-metal inorganic compounds with ionic or covalent bonds. Examples of common uses are earthenware (unglazed pottery, glazed or unglazed), porcelain, and brick.
3. Non-technical ceramics are divided into three general groups: cement and concrete, baked clay, minerals, and stone. Technical ceramics are divided into fourteen groups: alumina, aluminum nitride, beryllia, bio-glass ceramics, boron carbide, calcium phosphate, carbon and graphite, magnesia, mullite, silicon carbide, silicon nitride, steatite, tungsten carbide, and zirconia.
4. Fibers and particles are used as reinforcement materials in different types of composite materials. Fibers and particles are divided into five groups: ceramic and glass fibers, ceramic particles, metal fibers, natural fibers, and polymer fibers.
5. Hybrids can be used as different types of composite materials and as thermal insulation parts. Hybrid materials are divided into four groups: composites, foams, honeycombs, and natural materials. Composites and foams can be made from metallic, ceramic, or polymer-based matrices.
6. Metals and alloys are divided into seven groups: ferrous (steel, cast iron, etc.), magnetic (AlNiCo, SmCo, etc.), non-ferrous (Al, Cu, Cr, etc.), other metals (Ca, Sb, V, etc.), precious metal alloys (Au, Pt, etc.), rare earth metals (Ce, Nd, Sc, etc.), and refractory alloys (Mo, Nb, Ta, W, etc.).

7. A polymer is an object composed of very large molecules. Owing to their wide variety of possessions, polymers, together synthetic and natural, play a fundamental and universal role in daily life. Polymers have larger molecular masses than small-molecule mixtures. They produce exclusive physical possessions such as hardness, extreme elasticity, viscoelasticity, and a tendency to form amorphous and semi-crystalline structures instead of crystalline structures.
8. Polymers are materials connected by covalent bonds and dominant van der Waals bonds. Polymeric materials are divided into two groups: elastomers and plastics.
9. An elastomer is a polymer that contains viscosity and elasticity in its structure. Elastomers begin to open cross-links during mechanical stress, allowing the chains to stack in the direction of tension, so they have the capacity to extend up to 10 times. When the stress is eliminated, the deformation disappears, and they return to their previous length. Elastomers are usually thermosetting but can also be thermoplastic.
10. Plastic consists of elements called monomers, for instance, carbon (C), hydrogen (H), oxygen (O) and nitrogen (N). Plastics are not found in nature; they are obtained by human intervention in the elements in nature. It is obtained by reacting to monomers using a catalyst under a certain temperature and pressure. Plastics are divided into two main parts: thermoplastics and thermosets.
11. Thermoplastic is a plastic polymer material that can be molded at a certain temperature and solidifies after cooling. Polymer chains combine by intermolecular forces, which rapidly undermine with increasing temperature, forming a viscous liquid. Thermoplastics can be reused when heated due to their weak bonds, meaning they are suitable for recycling.
12. A thermoset is a thermosetting polymer and is a material attained by permanently hardening the resin. During the curing process, cross-linking occurs between polymer chains.
13. Polymers have a wide variety of uses. Among the industrial usage areas, we can count textiles, electronic goods, the automotive industry, healthcare, building materials, food and beverage industry, and sports equipment. In textile, we see jeans and T-shirts made of cotton fabric among the most used clothing items. Cotton thread is a natural polymer produced from cellulose. In the electronics industry, polyethylene (PE) or polyvinyl chloride (PVC) is used in cable production. CD players and computer motherboards are also made from polymers and epoxies. Rubber, the basic material of automobile tires, is a polymer that can be produced both synthetically and naturally. Impact-resistant ABS polymer is used in the fabrication of parts, for example, bumpers and mudguards. Vehicle headlights are made of polycarbonate, a transparent polymer. The use of plastic in the medical equipment industry is becoming widespread. Syringes, gloves, bandages, and goggles are just a few. Gloves used in laboratory and surgical environments are generally made of latex. Latex is a rubber-based synthetic polymer. Disposable syringes are among the medical supplies and are usually made of polyethylene or polystyrene. Plastic materials or plastic-based composite materials can be seen in every field of building materials. The most used infrastructure product is poly (vinyl chloride) (PVC) based plastic water pipes. PVC polymer can also be used as roof and floor covering. In our kitchens, plastic trays are usually made of polyethylene. The glasses we use to drink water from dispensers are made of polypropylene or polystyrene. Plastics produced in food and beverage packaging have created a separate and very large plastic sub-industry. Polymers are widely used in the production of sports equipment. Nylon and polyurethane are the most used plastics, especially in sports shoes. SBS or Polyurethane polymers are generally used in shoe soles. Shoelaces are also made of nylon or cotton.

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