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# Acrylate Polymers for Advanced Applications

*Edited by Ángel Serrano-Aroca and Sanjukta Deb*



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#### Contributors

Thomas Swift, Ramesh Rudrapati, Kingsley Kema Ajekwene, Ángel Serrano-Aroca, Sanjukta Deb

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# Meet the editors



Professor Serrano-Aroca holds a PhD in Chemical Engineering and currently teaches bioengineering at the Universidad Católica de Valencia San Vicente Mártir. His research interest is developing medical materials and devices for advanced applications such as antimicrobial therapy, tissue engineering, wound healing, etc. He is currently Vice Dean of Biotechnology and Principal Investigator of the Biomaterials and Bioengineering Lab at the Centro de Investigación Tranlacional San Alberto Magno.



Professor Sanjukta Deb is a professor in biomaterials science at King's College London. The main theme of her research is developing innovative biomaterials and biomimetic scaffolds to restore function of traumatized/diseased tissue for clinical translation. She is currently the Chair of the Royal Society of Chemistry: Biomaterials Chemistry interest group and the ex-President of the UK Society of Biomaterials.

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# Preface

The field of polymer science and engineering includes research in multiple disciplines including chemistry, physics, engineering, biotechnology and medicine, among many others. Polymers include synthetic polymers such as plastics and elastomers, and natural biopolymers. Acrylates are synthetic polymers classified as thermoplastic resins used in a great number of industrial products, ranging from bone cement or contact lenses in biomedical applications to artificial nails, diapers, cosmetics, orthopaedics, paints and coatings, adhesives and textiles in other industries. Acrylates are made from acrylate monomers that contain vinyl groups and possess a wide range of properties ranging from super-absorbency, transparency, flexibility, toughness and hardness. Currently, there are many polymers produced from acrylate monomers. Here we analyse how their solution properties are pH dependent and the effect of the state of ionisation affects their solution properties. Acrylate polymers such as poly (acrylic acid) and poly (methacrylic acid) are polyelectrolytes, with ionisable functional groups that render them stimuli responsive, changing their hydrodynamic volume. Poly (acrylamide) is a mass-produced acrylate material utilised in a variety of industrial applications, often produced from an anionic and cationic co-monomer. Poly (N-isopropyl acrylamide) is a thermally responsive acrylate material with applications in smart bioengineering. Other advanced applications have been developed with polycarbonate antiballistic and acrylic heat resistant glass due to their important properties such high impact strength, transparency, reflective index and chemical reactivity. In the field of biomedicine, acrylic-based materials have been used over many years due to their versatile properties. In fact, many different acrylate polymers have been approved by the US Food and Drug Administration (FDA) for biomedical use in humans. Thus, they are frequently used in orthopaedics, ophthalmologic devices, antimicrobial therapy, tissue engineering applications and dental applications. Many sophisticated methods and techniques have been developed in the last few decades in order to expand their potential applications in the biomedical industry. Thus, successful scientific enhancements have been achieved with respect to mechanical performance, electrical, thermal properties, diffusion, biological behaviour, antimicrobial activity and porosity. Multicomponent acrylate-based polymeric platforms have been developed as interpenetrating polymer networks or in combination with other materials such as fibres, nanofibres, carbon nanomaterials and its derivatives and/or other different types of nanoparticles in the form of composite or nanocomposite biomaterials. Furthermore, in bioengineering, acrylic porous supports (scaffolds) need to be synthesised with the necessary degree, type and morphology of pores using advanced technological fabrication techniques.

This book presents five chapters in two sections on recent information about acrylate polymers paying more attention to their properties and advanced applications.

The first section presents three chapters dealing with the properties and applications of acrylate-based materials. The first chapter focuses on four commonly-used examples of acrylate polymers and studies how their solution properties are pH dependent and how their state of ionisation can affect their solution properties. The second chapter deals with polymer material classification as acrylic heat resistant glass

and polycarbonate antiballistic glass. The third chapter highlights the characteristic properties and applications of acrylates, its derivatives and copolymers.

The second section of this book contains two chapters on acrylate-based materials in biomedicine and bioengineering. The first chapter of this section presents a review of acrylic-based materials used in biomedical and bioengineering applications and the strategies developed so far to enhance their physical, chemical and biological properties. The second chapter focuses on acrylic-based hydrogels as biomaterials. This book provides information about acrylate polymers that we expect to be very useful for researchers working in this exciting area.

**Dr. Ángel Serrano-Aroca**

Professor,  
Biomaterials and Bioengineering Lab,  
Centro de Investigación Traslacional San Alberto Magno,  
Universidad Católica de Valencia San Vicente Mártir,  
Spain

**Dr. Sanjukta Deb**

King's College London,  
UK



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Section 1

# Acrylate Polymers: Properties and Applications

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# Properties and Applications of Acrylates

*Kingsley Kema Ajekwene*

## Abstract

Acrylates are the esters, salts and conjugate bases of acrylic acid with its derivatives. They are made from acrylate monomer, which usually comprises of esters which contains vinyl groups, that is two carbon atoms that are double-bonded to each other, and directly attached to the carbonyl carbon of the ester group. Acrylates possess very diverse characteristic properties ranging from super-absorbency, transparency, flexibility, toughness and hardness, among others. These kinds of materials are used in sundry applications such as diapers, cosmetics, orthopedics, paints and coatings, adhesives, textiles, and many biomedical applications such as contact lenses and bone cements. This book chapter highlights the characteristic properties and applications of acrylates, its derivatives and copolymers.

**Keywords:** acrylates, methacrylates, super-absorbency, transparency, coatings, properties, applications

## 1. Introduction

Acrylates (or polyacrylates), belong to the family of vinyl polymers made from acrylate monomers. They are the esters, salts and conjugate bases of acrylic acid and its derivatives, of which methacrylates are the most common members. Its monomers are esters containing vinyl groups, which comprises two carbon atoms that are double-bonded to each other and directly attached to the carbonyl carbon of the ester group. This makes acrylates to be bifunctional in nature: the vinyl group is susceptible to polymerization, hence; carbonyl group carries myriad functionality using alcohols or amines [1–9]. The resulting polymers are characterized with a high molecular weight with physical and chemical properties that depend on the lateral substituents of the polymeric chains [10].

Acrylates are important class of polymers that are rubbery, soft and tough. They are well-known for their good impact toughness and resistance to breakage, transparency, elasticity, fairly good heat and oil resistance. They have also the capacity to endure a temperature of 170–180°C when they are in oil, exposed to dry heat or non-surfactant suspending agents that have anti-static binding abilities and film-forming. They also have good weatherability and ozone resistance due to the absence of double bonds in their backbone. Their glass transition temperature ( $T_g$ ) is usually well below the room temperature [1–4].

Acrylate polymers are commonly used in dentistry and many other biomedical applications [11], cosmetics and artificial nail products such as eyelashes, nail enhancing polishes, nail builders, artificial nails and to help artificial nails mold to the natural nail plate as an adhesive, hair fixatives, in marine phytoplankton as a

poisonous defense against predators such as protozoa, and oil seals and packaging that are related to automobiles [1–4, 8].

Acrylate monomers include ethyl acrylate, ethylene-methyl acrylate, methyl methacrylate, 2-chloroethyl vinyl ether, 2-hydroxyethyl acrylate, hydroxyethyl methacrylate, butyl acrylate, trimethylolpropane triacrylate (TMPTA).

The preparation of acrylate polymers usually involves the treatment of acrylic acids with the corresponding alcohol in the presence of a catalyst [1–4].

## **2. Properties of different types of acrylates**

### **2.1 Polyacrylic acid**

Polyacrylic acid (or 2-propenoic acid) is the simplest acrylate polymer  $(C_3H_4O_2)_n$ .

Polyacrylic acid polymers are usually produced from acrylic acid that is obtained from propene (a byproduct of ethylene and gasoline production). Acrylic acid polymer is used as thickening agent in acidic conditions because it is highly water dispersible and its dispersion in water thickens with the increase of pH [5].

Polyacrylic acid and related acrylates are regarded as unusual polymers because they absorb water very freely. They soak up water in multiples of their own weight with no difficulty. This means that even as a little grams of the polymer can absorb a cup of liquid, lock it in and hold it up tightly. Such polymers with this characteristics are termed as “super-absorbers”. Therefore, it has found usefulness in diapers, especially baby diapers. In diapers, polyacrylic acid absorbs all the liquids that little babies excrete and deposit in it. The super-absorbency of polyacrylics is advantageous in that way that they are less messy and more hygienic because the mess is locked up in the polyacrylic acid polymer and babies feel comfortable while their parents take their time to change the diapers [1–4]. That is why babies that use diapers of this sort do not get unpleasant skin rashes compared to those using napkins.

Acrylic acids form corresponding esters when reacted in the presence of an alcohol. Acrylic acid and its associated acrylates play important roles in the manufacturing of plastics, diapers, adhesives, floor polishes, nail varnishes/polish, paints, coatings and adhesives of various types [12].

With its film-forming characteristics, it serves as a film-forming agent that is used to obtain continuous films on the nail, skin or hair. These characteristics enable them to be used in various applications including eyeliner, liquid makeups, mascaras, nail polish, sunscreens, lipsticks and skin care products (creams, lotions, etc.).

They also find major applications in coatings and paints such as solvent-borne coatings, emulsion paints, interior and exterior water-based paints, and printing inks for applications that need quick drying rates such as auto based lacquers and industrial coatings. They are also used in pressure sensitive adhesive formulations—from low adhesion that are barely tacky to very high tack that can bond permanently to substrates, textiles, automotive products, leather finishing, tape adhesives, high-temperature-resistant and oil-resistant elastomers. They can also be used as plasticizer to improve the plasticity of brittle and rigid plastics that are largely used in the automotive industry for dampers, hoses, gaskets and seals that usually function under long-term exposure to hydrocarbon oils and elevated temperatures [1–4].

### **2.2 Methacrylate**

Methacrylate is often used as a generic term for methacrylate and acrylate. Methacrylate refers to derivatives of methacrylic acid or methyl ester of acrylic acid.

These derivatives include the acid form,  $\text{CH}_2\text{C}(\text{CH}_3)\text{CO}_2\text{H}$  or  $(\text{C}_4\text{H}_6\text{O}_2)$ , the salts such as  $\text{CH}_2\text{C}(\text{CH}_3)\text{CO}_2^- \text{Na}^+$  and the esters (e.g.  $\text{CH}_2\text{C}(\text{CH}_3)\text{CO}_2\text{CH}_3$  or methyl methacrylate) and their corresponding polymers.

Methacrylates can form polymers easily because their double bonds are usually very reactive. The polymers exhibit a characteristic water solubility which is pH-dependent. This behavior makes them useful as coating agents in drug delivery systems. It is mostly used as a vehicle for obtaining amorphous systems and solid dispersions, such as nanoparticles, microparticles and microspheres to increase the solubility of low solubility drugs [1–4, 12, 13].

Poly(methacrylate) hydrogels have found useful applications in medical devices, especially for ocular applications (e.g. intraocular lenses and contact lenses), and as cell delivery and drug delivery systems. They have found potential applications as intelligent hydrogels for biomimetic sensors, controlled drug release, analyte-sensitive materials, intelligent polymeric membranes and micro-fluidic devices [1].

### 2.3 Poly(methyl methacrylate)

Poly(methyl acrylate) (PMA) is produced with the methyl acrylate (MA) monomer, also called as methyl prop-2-enoate, methyl propenoate or methoxycarbonylethylene. However, poly(methyl methacrylate) (PMMA) is synthesized by polymerization of methyl methacrylate (MMA), which is an acrylate monomer in which one carboxylic acid hydrogen and vinyl hydrogen are replaced by a methyl group.

Methylacrylate is produced by the reaction of esterification with methanol under acid catalysis (acidic ion exchangers, p-toluene sulfonic acid, sulfuric acid) or by pyrolysis of methyl lactate in the presence of ethenone (ketene), the debromination of methyl 2,3-dibromopropanoate with zinc or dehydration of methyl lactate over zeolites as well as vapor-phase oxidation of nickel tetracarbonyl-catalyzed hydrocarboxylation of acetylene and propene or 2-propenal with oxygen in the presence of methanol with carbon monoxide which also yields methyl acrylate. Reacting methyl formats with acetylene in the presence of a transition metal catalyst can also yield methyl acrylate [1–4, 9, 13].

PMMA is a linear chain polymer that is characterized by its hydrophobicity, relatively superior light admittance (transparency), amorphous disposition at a molecular level, and glassy feature at room temperature that makes it a strong, hard and clear plastic under the “Plexiglas” trade name [10]. However, it can also become a white rubber at room temperature. The hardness or softness is determined by the numbers of methyl groups present which determines chain mobility and hence the softness and flexibility (i.e., the extent of the free movement of the polymer chains around each other). The softer the polymer, the better the mobility and pliability. Therefore, a polymer will be soft or hard depending on its easy or difficult movement.

MMA is used as the monomer resin in dental materials, in windscreen repair kits and as bone cement for fixing prosthetic devices in orthopedic surgery where it provides a buffering effect, absorbing shock from forces acting upon the bone because of its optimal ability to efficiently distribute stresses and interface strain energy [10]. In its pre-processed form, it is usually a colorless liquid characterized by an acrid odor. It is mainly produced to make acrylate fiber, which is used in weaving synthetic carpets. It also serves as a reagent in the synthesis of various pharmaceutical intermediates. PMMA is used in the preparation of 2-dimethylaminoethyl acrylate by trans-esterification with dimethyl aminoethanol. It is used as a co-monomer with a variety of vinyl and acrylic monomers in the polymerization of various polymers. When using MA as co-monomer,

the resulting acrylates are more brittle and harder than those with homologous acrylates. It is also a good dienophile.

PMMA is a non-degradable polyacrylate, which is the most commonly utilized non-metallic implant material in orthopedic surgery and it is also used as an essential ingredient in making dentures. PMMA can be applied as a bone fixing material in the implanting of orthopedic prosthetic materials for shoulders, knees and hips repairs. PMMA-based bone cements can be added to ceramics or bioactive glasses to impart mechanical properties and modify the curing kinetics and as well as loading some dosages of antibiotics in the PMMA cement to decrease the risk of related prosthesis infection. Due to its outstanding bio- and hemo-compatibility and ease of modification, PMMA is usually used in several medical devices, including dialyzers and blood pumps. The optical properties make it a good material for hard contact lenses and implantable ocular lenses. PMMA also offers coloring and physical properties that are beneficial for denture fabrication [14].

PMMA can be introduced into cosmetic products as beads (porous and non-porous beads) to enhance its performance [13, 15]. The non-porous beads of PMMA impart very high resistance to organic solvents, which allows its usage in nail varnish (mattifying and hardening effects). It has a supple structure and low oil absorption making it a good binder for pressed powders. In addition, they are absolutely transparent on the skin top giving rise to an excellent volume in mascaras, velvet touch effect and ball-bearing effect. Due to their non-porous nature, they do not absorb moisture and sebum neither do they dry the skin. Thus, it makes them ideal candidates for normal, dry and sensitive skin. They are versatile compounds, which can provide soft feel on the skin, optical effects and unique textures to achieve innovative formulations for skin care and make-up [15].

The porous beads of PMMA are cross-linked and have very high specific area that facilitates the enhancement of absorption of sebum and sweat, occasioning a matte and dry influence on the skin (preventing the sticky skin feel after the application) and optically suppressing makeup smudging [15].

## **2.4 Polyacrylamide**

Polyacrylamide (PAM) readily dissolves in water. Therefore, this polymer is used industrially in many applications where it serves such purposes. In addition, the cross-linked form of polyacrylamides can also absorb water to form gels without dissolving. The absorbed water in the formed gels of cross-linked polymer renders them soft and thus suitable for use in biomedical products such as soft contact lenses [1–4].

Another application of PAM gels include soil conditioner to stabilize soil aggregates as well as flocculate suspended particles and furrow irrigation where it reduces erosion and runoff while improving soil and water quality and water-use efficiency. They are also used to reduce surface sealing and crusting as well as erosion in certain agriculture and sprinkler irrigation systems in a cost effective way. PMA is also used to stabilize steep slopes in construction, highway cuts, and other disturbed soils in geo-construction [16].

## **2.5 Polyacrylonitrile**

Polyacrylonitrile (PAN) is a derivative of acrylic acid where the carboxylic acid group is replaced by the related nitrile group and presents the molecular formula  $(C_3H_3N)_n$ .

PAN is a semi-crystalline polymer and though it is a thermoplastic, it does not melt under normal conditions. Its degradation occurs before it melts and its melting

is usually observed at above 300°C. When this polymer is heated up to 200°C, it can be transform into a rigid structure with a release of energy, an occurrence referred to as cyclization. Above the cyclization temperature, this polymer undergoes oxidation, a scenario that confers non-flammability on it. If PAN is heated to above 1000°C under inert atmosphere, it gives a product with a percentage of carbon greater than 90%. This property makes it usable in carbon fiber production.

Some major characteristic properties that render PAN special compared to other polymers include the fact that it is the most resistant polymer to degradation by ultraviolet rays and sunlight and it is highly chemically unreactive and resistant to most organic acids and solvents. In addition, this polymer can be attacked only by concentrated solutions of alkalis and highly polar liquids. PAN in the form of acrylic fiber is resistant to breakages, is soft and comfortable, possesses high thermal insulation properties, and it does not melt maintaining its morphological structure when it is heated. This last property of PAN is utilized for the production of insulation fibers, flame retardant fibers, carbon fiber and blankets for filtration of hot gases [17].

Due to its special properties such as stability to UV degradation, low density, high strength and modulus of elasticity, thermal stability, non-fusibility and chemical resistance, PAN is an important polymer for a wide range of applications. Thus, it is used in textile applications due to its wool-like characteristics, in the making of carbon fiber, filtration membranes, fibers for cement reinforcement, sails for yachts, awning fabrics in outdoor applications, specialist fibers for acoustic and thermal insulation, anti-flame fibers and in the production of felts for hot air filtration systems [17, 18].

Copolymers containing polyacrylonitrile, which are flame-retardant, are used as fibers to make knitted clothing, like socks and sweaters, as well as outdoor products like tents. Poly(acrylonitrile-*co*-butadiene-*co*-styrene) (ABS) and Poly(styrene-*co*-acrylonitrile) (SAN) are used as plastics. ABS is a lightweight and very strong polymer. It is so light and strong enough to be used in the production of automobile body parts. Thus, this material render automobiles' lighter using less fuel and thus polluting less [1–4].

The strength of ABS emanates from the nitrile groups that are present in its acrylonitrile units. The nitrile groups are very polar; hence, they can be attracted to one another. This occurrence permits opposite charges on the nitrile groups to stabilize one another. This strong attraction holds ABS chains very tightly, thus, it makes the material very strong. Furthermore, the rubbery polybutadiene present in it makes ABS a tough polymer [1–4, 19].

## 2.6 Ethyl acrylate

Ethyl acrylate (EA), also named as ethyl propenoate, ethyl prop-2-enoate, acrylic acid ethyl ester or ethyl propenoate, presents the molecular formula  $(C_5H_8O_2)_n$ .

Ethyl acrylate is the ethyl ester of acrylic acid. It is a colorless liquid with a distinctive unpleasantly pungent odor and it is mainly used in the production of paints and textiles, especially non-woven fibers. EA can also be used as a reagent during the synthesis of various pharmaceutical intermediates.

Ethyl acrylate is prepared by acid-catalyzed esterification of acrylic acid that is usually produced by oxidation of propylene. It can also be prepared from ethanol, carbon monoxide and acetylene by a Reppe reaction.

EA is used in the manufacture of polymers including rubber, plastics, denture material and resins. It is used as a reactant for alkyl acrylates (acrylic esters) by trans-esterification with higher alcohols through basic or acidic catalysis.

Other acrylate monomers: 2-ethyl hexyl acrylate (obtained from 2-ethyl-hexanol) is used in pressure-sensitive adhesives; cyclohexyl acrylate (obtained from cyclohexanol) is used in automotive clear lacquers; 2-hydroxyethyl acrylate (obtained from ethylene glycol), which is crosslinkable with di-isocyanates to form gels, is used with long-chain acrylates as co-monomer in comb polymers for the reduction of the solidification point of paraffin oils; 2-dimethylaminoethyl acrylate (obtained from dimethylaminoethanol) is used in the preparation of flocculants for sewage clarification and production of paper [8, 13].

Ethyl acrylate is a reactive monomer. Therefore, it is useful in the enhancement of the cleaning effect of liquid detergents, used as gastric juices tablet covers, in paper, paints and adhesives, textile and leather auxiliaries together with cosmetic and several other pharmaceutical products. EA is also used as a flavoring agent.

### **2.7.2-Ethyl hexyl acrylate**

2-Ethyl hexyl acrylate, also named as 2-ethyl hexyl prop-2-enoate or abbreviated as 2-EHA with the molecular formula  $(C_{11}H_{20}O_2)_n$ , is a chemical compound that belongs to the acrylates' family. It is a colorless liquid, which has a sweet odor and can be prepared by the esterification of racemic 2-ethyl hexanol and acrylic acid in the presence of the hydroquinone polymerization inhibitor with a strong acid such as methane-sulfonic acid by reactive distillation using the toluene azeotroping agent.

2-Ethyl hexyl acrylate easily and readily polymerizes. The polymerization of this monomer can be initiated by heat, peroxides, light or even by contaminants. In the presence of strong oxidants, 2-EHA reacts violently with the tendency to form explosive mixtures when exposed to air at temperatures above 82°C (180°F). The chemical, physical and toxicological properties, however, can be greatly modified by additives or stabilizers. 2-Ethylhexyl acrylate is one of the most important base monomers for the production of acrylate adhesives [13].

### **2.8 Hydroxyethyl methacrylate**

Hydroxyethyl methacrylate (HEMA), also named as 2-hydroxyethyl methacrylate, 2-hydroxyethyl-2-methylprop-2-enoate, glycol methacrylate, glycol monomethacrylate, 2-(methacryloyloxy)ethanol or ethylene glycol methacrylate, presents the molecular formula  $(C_6H_{10}O_3)_n$ .

HEMA is a colorless and viscous liquid, which can readily polymerize and used as monomer for the production of various types of polymers. It is hydrophobic in nature, nevertheless, in the form of hydrogel, if exposed to water, it swells as a result of hydrophilic pendant group. HEMA is capable of absorbing from 10 to 600% of water relative to its dry weight depending on its chemical and physical structure. For this reason, it is usually used in the production of soft contact lenses [13].

When treated with polyisocyanates, HEMA makes a crosslinked polymer, an acrylic resin that is a useful component in some paints. HEMA can also be used as a matrix with 40 nm silica particles for 3D glass printing. It is one of the several polymeric hydrogels that are biocompatible with adjustable mechanical properties including resistance to crack propagation [20]. As the first hydrogel ever used for biomedical application [20, 21], it has been utilized in the production of stents and catheters [21]. Its porous structure eases the diffusion of fluids including oxygen making it suitable for fabrication of hydrophilic contact lens and artificial cornea prostheses [20].

## **2.9 Poly(2-hydroxyethyl methacrylate)**

Poly(2-hydroxyethyl methacrylate) (PHEMA) is one of the major biomaterial components of most soft contact lenses and is also part of intraocular lenses because of their inherent optical properties [21]. This is due to their hydroxyl groups (–OH groups) being free. PHEMA hydrogels contains very high amounts of water, also posing hydrophilic properties [22, 23], facilitating the diffusion of oxygen and solutes. That is why oxygen can gain access to the eyeballs through its gel aqueous phase without any hindrance in contact lenses. Lenses that are produced with PHEMA as one of the major constituting materials. Thus, they are widely used because the polymer has a unique blend of good stability to varying conditions of pH and mechanical properties, ionic strength and temperature [21]. Considering its suitability for ocular lenses, PHEMA has exhibited excellent biocompatibility. Hydrogels made from PHEMA and its co-polymers have been critically employed for biomedical uses and considered for controlled drug delivery applications. PHEMA gels have been used in several attempts to reconstruct nasal cartilages, female breasts, as artificial corneas and as wound dressings.

## **2.10 Butyl acrylate**

Butyl acrylate (BA), also called as butyl prop-2-enoate, n-butyl acrylate, butyl ester of acrylic acid or butyl-2-propenoate, presents the molecular formula  $(C_7H_{12}O_2)_n$ .

BA can be synthesized in various different reactions. Thus, 1-butyl alcohol, acetylene, carbon monoxide, hydrochloric acid and nickel carbonyl can react to yield butyl acrylate. Other chemical route in the synthesis of BA comprises the reaction of methyl acrylate with butanol or acrylic acid.

Butyl acrylate is used in coatings, paints, adhesives, sealants, plastics, textiles, caulking materials and fuel [24]. Its derivatives could be used to improve the impact strength of other acrylic plastics, by incorporating them as impact modifiers [25].

## **2.11 Trimethylolpropane Triacrylate**

Trimethylolpropane Triacrylate (TMPTA), also named as 2,2-Bis[(acryloyloxy)methyl]butyl acrylate, presents the molecular formula  $(C_{15}H_{20}O_6)_n$ .

TMPTA is a tri-functional monomer, which is used in the production of adhesives, plastics, inks, anaerobic sealants and acrylic glue. Its usefulness stems from its low volatility and fast cure rate. It possesses good water, chemical, weather and abrasion resistance. The end products of TMPTA include hardwood floors, alkyd coatings, concrete polymers, compact discs, dental polymers, letterpress, lithography, automobile headlamps, elastomers, acrylics, screen printing and different plastic components for medical industry [3, 4, 6].

## **2.12 Sodium polyacrylate**

Sodium polyacrylate (NaPA), also named as poly (sodium prop-2-enoate), presents the molecular formula  $(C_3H_3NaO_2)_n$ . NaPA is a sodium salt of polyacrylic acid with broad application in consumer products, and structural engineering [26]. Though it is soluble in water, when processed into a chemically crosslinked polymer hydrogel, it would swell greatly in water [27]. This occurs as a result of the sodium carboxylate salt present in water and the interactions of the hydrogen



bonds between water and the crosslinked polymer. This super osmotic process of water absorption tagged this material as a super absorbent (also known as water lock) polymer (SAP) because it is capable of absorbing up to 100–1000 times its weight when exposed to water. When this polymer is blended with clay, it renders improved and controlled swelling properties [28].

Sodium polyacrylate is an anionic polyelectrolyte-based polymer comprising of carboxylic groups that are negatively charged in the main chain. There are other salts neutralized polyacrylic acids available in the market including potassium, lithium and ammonium. However, sodium neutralized polyacrylic acids are the most common form used in industry.

NaPA and other derivatives of polyacrylic acid have varied commercial and industrial applications: animal care (pet pads, horse urine odor absorbing materials, drown-free water source for feeder insects); topical health (paper and disposable diapers, sanitary wares and napkins); industry (waste liquid control, drilling fluids, concrete protections). environmental protection (geo-textiles for road constructions, anti-flood bags, excreta collection bags and containers); structural engineering application of concrete structures with sodium polyacrylate serving as an internal curing agent and exhibiting enhanced durability and strength performance [26]; biomedical field for drug delivery applications in ocular, nasal, buccal, gastrointestinal, epidermal and transdermal drug delivery system due to their biocompatibility and similarities with living tissues in the pharmaceutical industry [27]; other products such as wire and cables, water blocking, artificial snows, hot/cold gel packs, urine bags, toys, thickening agents, fragrance carriers, fire-retardant gels, anti-fogging packing materials and waterbeds.

### **2.13 Poly(N-isopropylacrylamide)**

Poly(N-isopropylacrylamide) (PNiPAAm) has gained significance as injectable polymer in cell and drug delivery due to the unique physicochemical properties. PNiPAAm undergoes phase separation resulting in the formation of an opaque hydrogel in response to a temperature above 32°C. This thermoresponsive behavior is as a result of strong hydrogen bonds between water molecules, the polymer and the specific molecular orientations of the bonds due to the molecular structure of this polymer.

### **2.14 N-butyl acrylate**

N-Butyl Acrylate (BA) is a soft monomer with low  $T_g$  and regarded as the largest-volume acrylate ester used in the preparation of all styrene acrylic copolymers, acrylic and vinyl acrylic. The other major acrylate esters include 2-ethylhexyl acrylate (2-EHA), ethyl acrylate (EA), and methyl acrylate (MA). Butyl acrylate is used as a soft-monomer to improve toughness and low temperature. The major applications for BA are in coatings and paints within the automotive and architectural field, sealants, adhesives and intermediates. Other areas of BA application include leather finishes, inks, caulks, textiles and papers.

Another important and growing usefulness of BA is in thermoplastic ethylene acrylate co-polymers (EAC). They are used as processing aid and impact modifier in thermoplastics to improve properties such as flexibility, toughness, molding characteristics, part appearances and low temperature properties. End use applications include adhesives, packaging and multilayer films. BA showcases superior photostability and is a preferred monomer where weatherability, with emphasis on low temperature applications especially at high altitudes, and sunlight resistance are required [24, 29, 30].

The combination of butyl acrylate with other polymerizable acrylate ester monomers allows the fabrication of copolymer compositions. This way, the performance of co-polymers can be tailored to meet a wide range of end-use requirements as it has the capacity to balance softness and hardness, block resistance and tackiness, low temperature flexibility, durability and strength, and other important properties required of products to meet end-use goals.

### **3. Possible risks associated with the use of acrylates**

The U.S. Environmental Protection Agency (US EPA) as well as the International Agency of Research on Cancer have classified some acrylates as a possible human carcinogen [11, 31]. For example, in dentistry, the use of acrylates as fillings may cause dental complications like pulpitis and periodontitis as a result of heat generation in the course of curing, as well as acidic and porous conditions [32]. Other exposures to acrylates have been related to eye, throat and skin reactions as well as more serious health consequences such as reproductive toxicity, cancer, neurological damage, development issues, organ system toxicity, cellular damage. Nonetheless, several acrylate polymers are currently successfully used or under research in a wide range of biomedical applications such as contact lenses, bone cements and scaffolds for tissue engineering [33–41].

### **4. Conclusion**

Acrylic polymers and co-polymers are currently widely used in industry in all kind of applications due to their chemical purity, stability, high heat resistance, sunlight resistance, excellent weathering, low temperature performance, water resistance and hydrophobicity. Acrylates have found application in the manufacture of co-polymers for coatings and paints, sealants, adhesives, textile fibers, printing inks. It is highly superabsorbent polymers and thus used in diapers. Thermoplastic acrylate co-polymers, in biomedicine and a variety of other advanced application areas.


### **Author details**

Kingsley Kema Ajekwene  
Department of Polymer and Textile Technology, Yaba College of Technology,  
Yaba, Lagos, Nigeria

\*Address all correspondence to: [kemaking@gmail.com](mailto:kemaking@gmail.com)

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This book presents five chapters, organised into two sections, on the latest developments in acrylate polymers materials in terms of properties, new ideas in design, synthesis and detailed applications. Section I presents three chapters on acrylate polymer properties and advanced applications such as pH dependence acrylate-derivative polyelectrolyte properties and polymer material classification as acrylic heat resistant glass and polycarbonate antiballistic glass. Section II includes two chapters on acrylic-based materials in the form of hydrogels, interpenetrated polymer networks, composites and nanocomposites for biomedical and bioengineering applications such as tissue engineering, antimicrobial therapy, orthopaedics and ophthalmologic devices.

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