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A review on poly (vinyl chloride) and its modification by crosslinking and grafting

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ABSTRACT

PVC is the most versatile vinyl polymer. As such PVC has limited uses but by adding various additives like plasticizers or by doing some chemical modifications, its properties are altered up to great extent. Various studies on PVC and its modification have been reviewed in this paper. FT-IR and TGA/DTA have been mainly used for the characterization. Thermal stability of the modified PVC was observed to be increased in maximum studies but in some cases it decreased after crosslinking. Properties of the PVC have been altered up to desired extent by using bifunctional crosslinkers to find wide applications like in construction, household applications, biomedical applications etc.

KEYWORDS

Polymer;
PVC;
Crosslinking;
Grafting;
FT-IR;
Thermal stability.

INTRODUCTION

Poly (vinyl chloride) i.e. PVC is one of the most versatile bulk polymers & widely used thermoplastic vinyl polymer. Vinyl polymers make up largest family of polymers. A thermoplastic, in general, is like wax which can be melted and shaped several times. The “thermoplastic” materials are either crystalline or amorphous. Advances in chemistry have made the distinction between crystalline and amorphous forms, since some materials like nylon are formulated both as a crystalline material and as an amorphous material. PVC is produced by polymerization of the monomer vinyl chloride which consists 57% of its mass of chlorine, thus creating a given mass of PVC requires less petroleum than most of the other polymers.

In terms of revenue generated, PVC is one of the most valuable products of the chemical industry. Globally, over 50% of PVC manufactured is used in construction. The ability to be used in either the rigid or soft (plasticized) forms doubles the market for this exceptionally safe material. The material is available in clear or coloured formats and it is durable, weatherproof, flame resistant with good overall mechanical properties. The material has come under attack by ‘Greenpeace’ and other environmental groups - all of which ignore the immense service that the material plays in the modern industrial society. PVC is claimed to be dangerous by some but it is the main material used for blood bags, medical tubing and has been responsible for saving countless lives. PVC has been the subject of more research than most other plastic materials and is acknowledged to be safe polymer by number of researchers.

HISTORY OF PVC

It was accidentally discovered on at least two different occasions in the 19th century, first in 1835 by

Henri Victor Regnault and in 1872 by Eugen Baumann. On both occasions, the polymer appeared as a white solid inside flasks of vinyl chloride that had been left exposed to sunlight. In the early 20th century, the Russian chemist Ivan Ostromislensky and Fritz Klatte of the German chemical company Griesheim-Elektron both attempted to use PVC in commercial products, but difficulties in processing the rigid, sometimes brittle polymer blocked their efforts. In 1926, Waldo Semon of B.F. Goodrich developed a method to plasticize PVC by blending it with various additives. The result was a more flexible and more easily processed material that soon achieved widespread commercial use[1].

The presence of chlorine in PVC hinders burning through formation of hydrogen chloride as it is incombustible (prevents access of oxygen to the combustion zone) and reacts with free radicals acting as terminator for the combustion propagation reactions. Thus by virtue of its chemical nature PVC achieves the kind of flame retardancy while this property is absent in other plastics. Various inorganic compounds including antimony oxide, zinc borate, alumina trihydrate, molybdenum oxide, compounds of lead etc have been used as fire stabilizers for PVC[2].

MODIFICATION OF PVC

As such PVC has limited uses but by adding various additives like plasticizers or by doing some chemical modifications, its properties are altered up to great extent to find wide applications in various fields.

To provide the extra desired physical or chemical properties in a particular polymer, some specialty additives are added, known as polymer additives. Butylated hydroxytoluene (BHT) is added to get antioxidant property in the polymer. Quaternary ammonium salts (R_4N^+ salt), or carbon black is added as an antistatic agent. Epsom Salts ($MgSO_4$) provides flame Retardancy. Hexane, sodium bicarbonate, CFC's are added to get foaming property. Fatty acids provide lubricating action. Hydroxybenzophenone can be added as Ultraviolet stabilizers. Sulfur is used as vulcanizing agents. Organo-titanium compounds or silanes as coupling agents and di-iso-octyl phthalate are added as plasticizers[3].

Crosslinking and grafting are very useful techniques for chemical modification of any polymer. Again, the advances in chemistry make it possible for a chemist to construct a material to be either thermoset or thermoplastic. The main difference between the two classes of materials is whether the polymer chains remain "linear" and separate after molding (like spaghetti) or whether they undergo a chemical change and form a three dimensional network (like a net) by "cross-linking". Crystallinity of the polymer also affect its properties. Crystallinity depends on the size of side groups and regularity of chain. Increased crystallinity enhances mechanical properties. Due to mobility of chains with respect to each other, crosslinking may affect viscoelastic property. Branching characteristics of a polymer affect the visocelastic and other physical properties. A study on branching characteristics of poly (vinyl chloride) was done by Kent B. Abbs[4]. Different ways to determine branched structures in PVC were discussed and a brief review of recent studies by[13] C NMR was given. The latter method has not only proved capable of elucidating the branching structure in PVC, but it also exhibited higher accuracy than conventional procedures. Common PVC grades were found to contain 2-3 pendant chloromethyl groups per 1,000 C and about 1 long branch was found in 2,000 C. Calculations showed that if long branches were associated with tertiary chloride which accounts for most of the observed degradation in the polymer. Reduced PVC exhibited annealing effects similar to those observed for LDPE (low dense polyethylene), although the number of branches was closer to that characteristic of HDPE (high dense polyethylene). Degraded PVC, which was reductively dehalogenated, exhibited a lower tendency to crystallize. This was believed to be the result of crosslinking reactions which decreased molecular mobility.

Thai Hoang & Neil Varshney[5] studied the thermomechanical characteristics (glass transition temperature (Tg), softening point (Ts), and linear thermal expansion coefficient) of rigid PVC crosslinked by a peroxide in the presence of trimethylolpropane trimethacrylate. Thermomechanical analysis (TMA) is an effective method for determination of dimension and thickness changes and thermal characteristics. They observed probe load of 0.05 N suitable to evaluate expansion, softening and contraction of the crosslinked PVC samples and higher mechanical strength of crosslinked PVC samples than those of the uncrosslinked samples.

In another study, PVC was crosslinked by a new peroxide (1,1-di-(t-amylperoxy) cyclohexane) (DAPC) in the presence of trimethylolpropane trimethacrylate (TMPTMA). It was also observed that the gel content and tensile properties of the peroxide crosslinked PVC samples were higher than those of the uncrosslinked PVC samples and they observed enhanced penetration resistance and service temperature of PVC by such type of peroxide crosslinking[6].

Fiaz M & Gilbert M[7] crosslinked the poly (vinyl chloride) by aminosilanes. They have shown that crosslinking improved penetration resistance of PVC due to formation of gel part in the material. Crosslinking of PVC and other thermoplastics has long been used as an effective way of improving mechanical properties at elevated temperatures. Peroxide cross-linking of rigid PVC was also studied by Bowmer T.N & his coworkers[8] in a different manner. They studied radiation crosslinking of plasticised PVC in the presence of polyfunctional monomeric additives and they employed the modified PVC in the manufacture of wire and cable insulation to improve strength and abrasion resistance. Ethacrylates and acrylates were found to be the most efficient polyfunctional monomers by them. They measured the extent of crosslinking by determining gel content by Soxhlet extraction in tetrahydrofuran. Mechanical properties were measured at 130°C and dynamic viscoelastic measurements were carried out to detect changes in the glass transition temperature (Tg). They also found that 15phr of TMPTMA and 0.3 phr of peroxide were optimum concentrations for maximising the extent of crosslinking and increase of tensile strength and Tg. The lower moulding temperature of 170°C was preferred to minimise thermal degradation.

Janos Dobo L[9] studied the radiation crosslinking of PVC in presence of monomeric additives, this process was both a grafting and a crosslinking reaction. For crosslinking additives, bifunctional esters of methacrylic acid were used. These monomers exhibit some features which make their use advantageous. Firstly, they are effective plasticizers for PVC, giving good contact with the PVC chains and thus facilitating the grafting reaction. Secondly, they are sensitive to radiation: their free radical yield (G-value) upon irradiation is high. In the classical concept of graft copolymerization this is regarded as a disadvantage. If we use a monomer with a high G-value, the free radicals are generated mainly in the monomer, giving rise to homopolymerization rather than grafting. But, things stand differently with bifunctional monomers like the dimethacrylates. The crosslinking of PVC in the presence of ethylene glycol dimethacrylate was studied by microcalorimetry, ESR and by structure investigation. A substantial part of the monomer polymerizes already during processing and storage. High concentration of free radicals of the methacrylate type may be frozen in the PVC matrix and become re-activated at higher temperature. The radicals disappear and reappear upon prolonged storage. The different stages of the grafting and crosslinking reaction were discussed.

Jagdish C & his coworkers[10] have developed a good process for forming a crosslinked PVC foam by means of radiation crosslinking.

Many attempts to improve the biocompatibility of PVC have been done. This includes polymer surface modification with endpoint attachment of heparin. PVC was chemically modified using poly (ethylene glycol) i.e. PEG to improve blood compatability[11]. Modification was carried out in two steps. First, PVC was aminated by treating with a large excess of an 80% aqueous solution of ethylenediamine. In the subsequent study PEG was grafted onto aminated PVC. The aminated PVC was then reacted with hexamethylene diisocyanate to incorporate the isocyanate group onto the polymer backbone. The isocyanated PVC was further reacted with PEG of molecular weight 600 Da. The thermal stability of the modified polymer was found to be lower by incorporation of PEG. Contact angle measurements on the surface of polymer films cast from a tetrahydrofuran solution of the polymer demonstrated that the modified polymer gave rise to a significantly hydrophilic surface compared to unmodified PVC. The solid/water interfacial free energy of the modified surface was 3.9 ergs/cm[2] as opposed to 19.4 ergs/cm[2] for bare PVC surface. Static platelet adhesion studies using platelet rich plasma showed significantly reduced platelet adhesion on the surface of the modified polymer compared to control PVC. The study showed that bulk modification of PVC using PEG can give rise to a polymer that possesses the anti-fouling property of PEG and such bulk modifications are less cumbersome compared to surface modifications on the finished product to impart anti-fouling properties to the PVC surface. Balazes D.J et al[12]. studied the surface modification of

PVC for biomedicinal purpose. They have presented a strategy to reduce bacterial adhesion based on the surface modification of medical grade poly (vinyl chloride) commonly used in endotracheal devices

Peng Liu & his coworkers[13] modified the PVC by using crosslinking as well as grafting process. They studied the poly (hydroethyl acrylate)-grafted cross-linked poly (vinyl chloride) particles via surface-initiated atom-transfer radical polymerization and competitive adsorption of some heavy metal ions on modified polymers. Poly (hydroethyl acrylate) (PHEA) was grafted from the surfaces of cross-linked PVC beads with their surface labile chlorines as initiation sites, using a copper-mediated surface-initiated atom-transfer radical polymerization methodology. The graft reaction exhibited first-order kinetics with respect to the polymerization time in the low-monomer-conversion stage. They achieved 190.4% of grafting (PG%) in 10 hrs.

Sang Phil Han et al[14]. did the systematic study of different processes and crosslinking agents which affect the crosslinked polymerization of PVC to be used for plastisol application. Two processes, microsuspension (MS) and seeded polymerization (SP), and two crosslinking agents, diallyl phthalate (DAP) and 1, 3-butanediol dimethacrylate (BDMA), were used. Microsuspension process was found to be much better for crosslinked polymerization of PVC for plastisol application.

Membrane separation processes have become an important unit operation in the chemical industry due to their many advantages. Commercially available separation membranes include cellulose acetate, polysulfone, polyvinylidene fluoride, polyamide, polyimide, polyvinyl alcohol, and polyvinyl chloride. Since PVC resin has excellent chemical resistance and is inexpensive, it is extensively utilized as a high-performance separation membrane. A method for modifying PVC separation membranes to improve its properties was developed by Tseng & his coworkers[15].

PVC, however, is a hydrophobic material, and the water flux of PVC separation membranes is not high. In addition, it is easy for impurities such as colloids to form sediment on the surface of the membrane during separation operations, resulting in a rapid decrease of the water flux of the membrane. The most direct and efficient method to overcome these drawbacks is to increase the hydrophilic property of the PVC separation membrane. Several other modifying methods have been proposed in the prior art literature. ZP Zhao et al[16]. observed a a high frequency discharge process to modify the PVC membrane with inorganic O_2, N_2, H_2, or He atmospheres to enhance the PVC membrane properties. As reported in Desalination, study done by F Vigo, et al[17], a Co^{60} gamma-ray was utilized to graft acrylonitrile onto the PVC and a phase inversion process was further utilized to prepare the modified PVC separation membrane. This process improves the permeation and separation characteristics of the membrane. Homogeneous heat treatment or a chemical treatment with peracetic acid could be used to modify PVC[18]. The modified PVC is then dissolved in N,N-dimethylformamide (DMF) to form a membrane casting solution. The casting solution is used to produce a modified PVC separation membrane by a phase inversion process. Since the resultant membrane has hydroxyl or acetate groups by virtue of the modification of the PVC resin, the hydrophilic property of the membrane is enhanced and the performance of the separation membrane improved. Izabela Wa Cerz et al[19]. reported that modified PVC membrane electrode could be used as enzyme biosensors for urea determination. The membrane material was PVC modified with 1, 4-diaminobutane. Chemical urease immobilization enabled the formation of a mono- and bimolecular enzyme layer directly on the pH sensor surface.

Gachter R et al[20]. developed a method for the use of amphiphilic polymers or copolymers for surface modification of reactive inorganic fillers like hydroxides, carbonates, silicates, dolomites etc. The invention concerns surface-modified active inorganic fillers modified with amphiphilic polymers or copolymers, as well as their use in polymers, especially PVC. It was found that active fillers like hydrotalcite for polymer masses can be strongly electostatically charged during grinding and therefore are difficult to transport or pack into sacks. These fillers also have a tendency to agglomerate and adhere to surfaces of the polymers.

Brown G et al[21]. studied the vinyl chloride homopolymer or copolymer composition containing a silane. They exposed graft homopolymer or copolymer to moisture to cross-link and to mold it suitably for the purpose of articles. They provided a method of moisture cross-linking poly (vinyl chloride) and vinyl chloride copolymers.

Polymer blends and alloys have received widespread attention for the last several decades. Polymer blends are defined as physical mixture of two or more polymers. They may be divided into different categories: so-called miscible blends in which the components exist in a simple homogeneous phase and immiscible ones in which the components exist in two distinct separated phases. Biju P.K et al[22]. studied the plasticizing effect of epoxidized natural rubber on PVC/ELNR blends prepared by solution blending. A series of polymer blends of poly (vinyl chloride) (PVC) and epoxidized liquid natural rubber (ELNR) were prepared and characterized by them. From tensile tests, it was found that elongation of the materials increased with degree of epoxidation. On the other hand, tensile strength and modulus of the material decreased with the epoxide content. A good plasticization effect was observed for samples of ELNR with 50% of epoxidation.. Baurer et al[23]. studied the another process for the production of PVC graft copolymers from ethylene/vinyl acetate copolymers and vinyl chloride.

Jan Oravec et al[24]. studied the crosslinking of PVC and NBR blends. The purpose of the work was to control the interfacial bonds between PVC and NBR using the ammonium salts of triazine thiols and dithiodimorpholine and thereby reveal the relation between the interfacial bonds and the final mechanical properties of products.

Abir S et al[25]. studied the inhibition of the degradation of poly (vinyl chloride) by its modification with 5-pyrimidine carbonitrile (1, 2, 3, 4- tetrahydro-4-oxo-6-phenyl-2-thioxo). The thermal stability of the modified polymer was improved significantly as compared with the unmodified polymer. The stability improvement was attributed to the replacement of the labile chlorine atoms by more stable thio groups. The modified polymer also showed a lower extent of discoloration against ultraviolet rays compared with the unmodified PVC. The stability of PVC when mixed with acid red4, morin and methyl blue in different concentrations was studied by Rizwan Hussain & Fazal Mahmood[26]. They employed differential thermal analysis for study of thermal stability. It was evident from the results that the presence of these dyes imparted a stabilizing effect on the polymer. The stabilization effect has been reported as heat of reaction for the main decomposition process of PVC

Tibor Kelen et al[27]. studied the reversible crosslinking during thermal degradation of PVC. PVC undergoes rapid crosslinking during thermal degradation. Evidently Diels-Alder addition of the conjugated polyenes plays an important role in crosslinking during thermal degradation of PVC. Use of Diels-Alder addition reaction was also made in the study done by Ajay Singh[28] for the grafting of maleic anhydride on crosslinked PVC. In the first step diethylenetriamine (DETA) was used as a crosslinker in the dimethylformamide (DMF) solvent. In the basic medium, during crosslinking PVC underwent dehydohalogenation reaction to create the unsaturation in the polymer. In the subsequent step maleic anhydride was reacted with conjugated crosslinked PVC followed by alkali and acid treatment to graft carboxylic group. H^+ (proton) of the carboxylic group could be exchanged with other cation to behave like cation exchanger.

Jiri Drexler et al[29]. studied the PVC compounds for photochemical crosslinking. The best was the combination of chlorthioxanthone and triethanolamine. Pentaerithroltriacrylate was obserbed to be the most effective crosslinking agent. Lead stabilizers gave the best heat stability and a higher rate of photochemical crosslinking than tin and antimony stabilizers.

Robert D et al[30]. studied the low-valent metals as reductive cross-linking agents and provided a new strategy for smoke suppression of poly (vinyl chloride). Several types of additives that contain transition metals can promote the cross-linking of (PVC) by a mechanism that apparently involves reductive coupling of the polymer chains. In solid PVC, the cross-linking occurs at 200°C.

Mojtaba Abbasian and Ali Akbar[31] did the study on metal-catalyzed living radical graft copolymerization of styrene initiated from arylated PVC. They examined the monomers such as styrene for graft copolymerization of PVC to improve the thermal stability of PVC. This graft copolymerization was carried out by atom transfer radical polymerization (ATRP). In this method PVC was condensed with toluene in mild condition (toluene as arylating agent), $AlCl_3$ complexed with nitrobenzene as catalyst and THF as diluent and *N*-bromosuccinimide as a brominating agent to obtain polymers with bromine group. This brominated PVC was used as a macroinitiator. This approach using a macro initiator is an effective method for the preparation of new materials.

Grohens J et al[32]. did the study on ultra-thin films of modified PVC. They prepared ultra-thin layers (*h*=50–150 nm) of PVC, functionalised in solution by thiophenol (t-PVC) and 4-aminothiophenol by spin-coating on silicon wafers. The glass transition temperature of these thin films was found to increase more strongly with the degree of modification in thin layer geometry than in the bulk. The Tg of the polymer layer increases with the cross-linking time more severely at a higher degree of modification but independently of the thickness of the layer indicating that the diffusion process is not altered in thin layers.

Garcia – Quesada J.C et al[33]. studied the the thermal decomposition behaviour of rigid PVC, crosslinked using bis (γ-trimethoxysilylpropyl)amine as crosslinking agent. Different thermal stabilizers (tin and lead based) have been used with different concentrations of crosslinking agent and the influence of these factors on the decomposition behavior in inert atmosphere was studied. The kinetic parameters have revealed a reduction in the apparent activation energy of the hydrogen chloride loss process, which has shown to be markedly dependent on the thermal stabilizer used.

Thomas Jando and Kunio Mori[34] also studied the crosslinking of PVC fibers with 2-dibutylamino-4,6-dimercapto-1,3,5-triazine in water. Crosslinking of PVC was done by nucleophilic substitution with 2-dibutylamino-4,6-dimercapto-1,3,5-triazine in the presence of sodium hydroxide and tetra-*n*-butylammonium bromide (TBAB) in water. The crosslinking reaction has been treated as a pseudo-first-order reaction. The rate constant (*k*) is 0.0230 min^{-1} at 90°C and the activation energy is 55.5 kJ mol^{-1}.

Franjo Ranogajec et al[35]. improved the polymer properties by radiation grafting and crosslinking with the aim of preventing the losses of stabilizers due to extractability or volatility. Glazyrin A B et al[36]. studied the properties and PVC composites.

HEALTH AND SAFETY ASPECTS

Many vinyl products contain additional chemicals to change the chemical consistency of the product. Main problem is related to Phthalate plasticizers, some of these additional chemicals called additives can leach out of vinyl products. Because soft PVC toys have been made for babies for years, there are concerns that these additives leach out of soft toys into the mouths of the children chewing on them. In January 2006, the European Union placed a ban on six types of phthalate softeners, including DEHP (Diethylhexyl phthalate), used in toys. In April 2006, the European Chemicals Bureau of the European Commission published an assessment of DINP (diisononyl phthalate) which found risk "unlikely" for children and newborns. Vinyl bags used in neo-natal intensive care units have also been shown to leach DEHP. In a draft guidance paper published in September 2002, the US FDA recognizes that many medical devices with PVC containing DEHP are not used in ways that result in significant human exposure to the chemical. However, FDA is suggesting that manufacturers consider eliminating the use of DEHP in certain devices that can result in high aggregate exposures for sensitive patient populations such as neonates. Other vinyl products, including car interiors, shower curtains, flooring, etc., initially release chemical gases into the air. Some studies indicate that this outgassing of additives may contribute to health complications, but this information is preliminary and further study is needed.

The environmentalist group Greenpeace has advocated the global phase-out of PVC because they claim dioxin is produced as a byproduct of vinyl chloride manufacture and from incineration of waste PVC in domestic garbage. Dioxins are a global health threat because they persist in the environment and can travel long distances. At very low levels, near those to which the general population is exposed, dioxins have been linked to immune system suppression, reproductive disorders, a variety of cancers, and endometriosis. PVC polymers generate polychlorinated dibenzodioxins (PCDDs) and dibenzofurans (PCDFs). The reactions include all of the ingredients and conditions necessary to form PCDD/PCDFs. It is difficult to see how any of these conditions could be modified so as to prevent PCDD/PCDF formation without seriously impairing the reaction for which the process is designed." In other words, dioxins are an undesirable byproduct of polymerizing PVC and eliminating the production of dioxins while maintaining the polymerization reaction may be difficult. Dioxins created by vinyl chloride production are released by on-site incinerators, flares, boilers, wastewater treatment systems and even in trace quantities in vinyl resins[37].

Vinyl chloride is known to be a human carcinogen based on sufficient evidence of carcinogenicity in human (IARC S.7, 1987). Vinyl chloride has been associated with tumors of the liver, brain, lung, and hematolymphopoietic system. A large number of epidemiological studies and case reports have substantiated the causal association between vinyl chloride and angiosarcoma of the liver. Several studies also confirm that exposure to vinyl chloride causes other forms of cancer, i.e., hepatocellular carcinoma, brain tumors, lung tumors, and malignancies of the lymphatic and hematopoietic system. Exposure to poly (vinyl chloride) dust was associated with an increased incidence of lung tumors in one study; the authors suggested that trapped vinyl chloride monomer was responsible[38].

APPLICATIONS

Today, cables made with irradiation crosslinked PVC insulation are used in the automotive industry and to supply high temperature equipment. Depending on the crosslinking additives, the irradiation crosslinked PVC component will be hard or soft. As a building material, PVC is cheap and easy to assemble. In recent years, PVC has been replacing traditional building materials such as wood, concrete and clay in many areas. As a hard plastic, it is used as vinyl siding, magnetic stripe cards, window profiles, gramophone records (which is the source of the term *vinyl records*), pipe, plumbing and conduit fixtures. The material is often used in Plastic Pressure Pipe Systems for pipelines in the water and sewer industries because of its inexpensive nature and flexibility. PVC is also widely used for producing pipes. In the water distribution market it accounts for 66 percent of the market in the US, and in sanitary sewer pipe applications, it accounts for 75 percent[39].

PVC is commonly used as the insulation on electric wires. The plastic used for this purpose needs to be plasticized. In a fire, PVC-coated wires can form HCl fumes; the chlorine serves to scavenge free radicals and is the source of the material’s fire retardance. While HCl fumes can also pose a health hazard in their own right, HCl breaks down on surfaces, particularly in areas where the air is cool enough to breathe, and is not available for inhalation. Frequently in applications where smoke is a major hazard (notably in tunnels) PVC-free LSOH (low-smoke, zero-halogen) cable insulation is used. The applicable building code should be consulted to determine the type of electrical wires approved for the intended use.

PVC is a fantastic creative medium. Its versatility makes it a popular choice for use by designers, many of whom welcome a modern alternative to traditional materials such as ceramic, metal and glass. PVC’s qualities of being available in many rigid and flexible forms, both durable and light weight, as well as its ability to be coloured and shaped, give designers opportunities that they would not have using any other material. PVC makes a major contribution to the quality, safety and cost-effectiveness of construction materials, as well as contributing to lower environmental impacts of completed projects. It is the most widely used polymer in building and construction applications.

PVC helps make our lives easier, safer, more convenient and more enjoyable. Products made from this versatile material offer a range of benefits to society and contribute to enhanced standards of living. The use of PVC compounds in medical devices manufactured during the last 50 years has demonstrated its great ability to satisfy the demanding requirements of the medical health care industry.

PVC makes a major contribution to the quality, safety and cost-effectiveness of modern road vehicles, as well as reducing their impact on the environment. In automotive applications it is the second most important polymer (after polypropylene) and gives many benefits which we now take for granted. In flat sheet form, Polyvinyl chloride is formed in a variety of thicknesses and colors. As flat sheets, PVC is often expanded to create voids in the material, providing additional thickness without additional weight and cost. Sheets are cut using saw and rotary cutting equipment. PVC is also used to produce thin, colored, adhesive backed films referred to simply as vinyl. These films are typically cut on a computer controlled plotter. These sheets and films are used to produce a wide variety of commercial signage products[40]. Unplasticized or rigid PVC is often used in the building industry as a low maintenance material, particularly in the UK, and in the USA where it is known as vinyl, or vinyl siding[41], over all the polymer “PVC” is involved in the sphere of every human life directly or indirectly.

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