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Introduction to Polycarbonates

In 1953, polycarbonate (PC) was discovered independently by Dr. H. Schnell of Bayer AG, Germany and by D. W. Fox of General Electric Company, USA. Since then, it has been used in a number of commercial and domestic applications. Polycarbonates have proved to be some of the best materials in domestic and industrial applications. By 1958, Bayer had begun producing polycarbonates with a brand name Makrolon. Other companies in the U.S. such as General Electric and Dow Chemical had also begun the production process. Companies such as AtoChem from France and Anic from Italy also joined the industry. Apparently, there are several companies which have joined the polycarbonate production industry from Japan, Korea etc.

A polycarbonate is a group of thermoplastic polymer which has an organic functional groups linked together by carbonate groups. They have a long molecular chain. They can be thermoformed easily. Their name is due to the carbonate groups which exist in their molecular structure.

Initially, polycarbonates were used in the manufacture of electrical and electronic appliances and glazing applications. However, its outstanding characteristics have been the main reason why it has gained popularity in a number of applications. In 1982, audio-CD were introduced after which the DVDs and Blu-ray technology followed. They are some of the most common products which depend on polycarbonates.

In mid 1980s, a number of fragile glass bottles were replaced by bottles, which were manufactured from polycarbonates. During this period, the PCs were used in the automotive industry to manufacture headlamps in the U.S. before being authorized in Europe by 1992. Apparently, they are used in a number of applications where they have substituted glass, especially, in building construction, military equipment, greenhouse construction, windscreens, etc.

The global market for polycarbonate sheets/resin/products has grown evidently in the recent past, more so, with its adaptability in the end user market. The polycarbonate market can be divided
into the following regions: Western Europe, Asia-Pacific, North America and Rest of the World. Some of the main industries in the polycarbonate market include:

1. Formosa Chemical & Fiber Corporation from Taiwan.
2. SABIC IP and Styron, which are U.S based companies.
3. Bayer Material which is based in Germany.
4. Teijin, Idemitsu Kosan, Mitsubishi Engineering Plastic and Mitsubishi Gas Chemical Co. from Japan among other key players in the polycarbonate market.

According to the Transparency Market Research, the polycarbonate market could reach a total of US$ 19.59 billion by 2020. This was after the market was valued at US$ 12.86 billion in 2013 when the Asia-Pacific region dominated this market with over 61% in volume.

This article will explore all aspects related to polycarbonate sheets such as properties, classification, applications and various forming processes. Essentially, it has been designed to provide more insight on this useful engineering product for both beginners and professionals.

Chemical bonding and structure

All the desirable mechanical and physical properties of polycarbonate materials are as a result of the chemical bonding and structure of polycarbonate elements. The bonding structure describes how various elements have been attracted together to form a tangible material. Carbon (C) is an important element in all polymers. Carbon has four valence electrons and shares other four electrons. As a result, it can form quite a number of covalent bonds. Furthermore, it can form a strong bond with long and strong chains.
To understand the basic properties of polycarbonates, it is prudent to analyze its overall structure. This polymer is made up of phenyl (the six-sided structure) and methyl (CH₃) groups. The basic elements include: carbon, hydrogen and oxygen. Each of these elements plays a significant role in the overall performance of the polycarbonate.

All these elements form part of the two major components of this polymer which are the Bisphenol A and carbonate. It is the above structure which repeats itself to form a polycarbonate resin or sheet. Normally, during the synthesis and analysis process, it is these compounds which are analyzed independently.

The Bisphenol A contains carbon, hydrogen and the phenyl group (aromatic rings). The phenyl group gets attracted to various molecules in the Bisphenol A which contributes to lack of mobility within the polycarbonate structure. This results in high viscosity and high thermal resistance. Since this prevents both mobility and flexibility in the overall structure of the
polycarbonate; it hinders the formation of crystalline structure. This makes this polymer amorphous in nature which contributes to its transparency.

The aromatic aromatic rings are hydrocarbon compounds with benzene ($C_6H_6$). It can be drawn as a ring with six carbon atoms.

![The details of an aromatic ring](image)

The structural strength of polycarbonate products is due to the covalent bonds which exist between all these elements. With analysis of the overall chemical structure of the polycarbonate, it is quite simple to understand why it possesses certain unique properties.

**Synthesis and manufacturing of polycarbonates**

**Synthesis of polycarbonates**

Synthesis of polycarbonates is an important process in industrial setup. In most cases, polycarbonates are synthesized from both phosgene and Bisphenol A using step-growth polymerization technique. In this process, the chlorine ions are eliminated each time as the polycarbonate monomers react.

In step reaction (condensation polymerization), the growth of polycarbonate chains is due to the reactions which take place between the molecular species. In polycarbonate synthesis, the Bisphenol A reacts with a predetermined volume of acceptors such as sodium hydroxide (NaOH) which results into a number of polymerization groups as shown in the figure below.
The first stage of the synthesis process

The above compound (deprotonated Bisphenol A) is reacted with Phosgene in the second stage of the reaction at a temperature between 25°C and 35°C. In this process, the polycarbonate monomer can be obtained while the catalyst (Pyridine) and chlorine anion is eliminated. This can be explained by the equation below:

\[ \text{Bisphenol A} + 2 \text{NaOH} \rightarrow \text{Diphenolate ion of Bisphenol A} + 2 \text{Na}^+ + \text{H}_2\text{O} \]

The second stage of the reaction in the synthesis process

In case more quantities of phosgene and Bisphenol A are to be reacted, there is a need to eliminate chlorine anions. Alternatively, the Bisphenol A and Diphenyl Carbonate can react at a temperature between 180°C and 220°C which yields polycarbonate and phenol molecules. It is important to note that this second option results in a lot of impurities. Moreover, the process requires higher temperature which may require advanced equipment, which increases the production cost.

Manufacturing of polycarbonates

Producing high quality polycarbonate at a cheaper cost is the ultimate goal of every polycarbonate manufacture. However, to make polycarbonate useful for various industrial and domestic applications, there are a number of stages involved. The quality of the end product will
be determined by the efficiency of this process. Normally, the manufacturing process involves transforming polycarbonate pellets to the desired shapes which can meet the desired objectives and goals. This may involve:

1. Melting the polycarbonate pellets to a desired temperature.
2. Adding various additives suppose certain properties of the polycarbonate is to be altered.
3. Forcing it under pressure into a die or mold. This process can be repeated severally until the desired shape is obtained.

There are two main types of manufacturing processes which are commonly and they include:

*Extrusion:* this is a manufacturing process which is used to fabricate polycarbonates and its alloys. Polycarbonates can be formed into different profiles such as profiles with uniform cross-section or continuous length. Such products can be used for roofing applications. In most cases, this process can be categorized as solid sheet, multi-wall sheet and profile extrusion. This produces different types of polycarbonate products which can be used for different applications. During the process, it’s important to consider the following key aspects:

1. The grade of polycarbonate product. A number of polycarbonate manufactures will try to produce as many grades as possible.
2. The extruder equipment and process involved. It should guarantee efficiency while saving on production costs
3. The processing parameters.

*Molding polycarbonate products:* this is a manufacturing process where the polycarbonate melts is pressed using the required shape. The final product is cooled while still in the mold. It is commonly used to produce computer and automotive parts.

The injection molding is commonly used in a number of industrial set up. Normally, there are a number of parameters which should be regulated to ensure that the final polycarbonate product meets the required specifications. These parameters include:

1. The dimension of the mold
In any manufacturing process, accuracy and tolerance are essential factors that every polycarbonate product manufacturer should consider. This is the main reason why all manufacturers are always cautious when they are constructing the mold.

Advantages and disadvantages of polycarbonates

Polycarbonate products are extensively used for a number of applications. This is due to the intrinsic properties of polycarbonates, which guarantee optimal performance. Some of the main advantages and disadvantages of polycarbonate products include:

Advantages of polycarbonate

Polycarbonates are virtually unbreakable. Consequently, they can withstand high magnitude of impact or force. This is mainly attributed to the overall structure of the PCs. It is for this that they are used to make bulletproof windows and anti-riot shields. They are also used to construct hurricane barricades and in glazing applications.

They can be designed to block ultraviolet radiation. This radiation can be harmful, more so, in greenhouses where it can a burning effect. The modern polycarbonate sheets have been designed to be ultraviolet radiation proof which makes them to be a perfect choice for glazing applications and overhead covers.

They have a lightweight. This makes the installation process easier than other materials such as glass which may require addition reinforcement of the overall structure. It reduces labor costs since they don’t require heavy machines for the installation process. In addition to these, they are associated with low transportation costs since all products to be shipped are charged per unit weight.
Versatility; polycarbonate products are generally versatile. This is due to the fact that they can withstand a wide range of weather conditions. They can resist fluctuating temperature and chemicals. This has been the main reason why they are used in harsh environmental conditions.

They are available in a wide range of shades. As much as polycarbonates can transmit over 90% of light, by improving their texture and shades they can guarantee privacy. The shades can be customized depending on the applications and the requirements of the end user.

Superb optical properties; this is the main reason why they are used to make vehicles wind screens, protective shields, skylights, greenhouses, etc. They are available in a number of configurations which can let only the required amount of light and heat while eliminating the ultraviolet radiations.

Disadvantages of polycarbonates

The polycarbonate products are not 100% perfect. They have certain disadvantages which include:

High installation costs; all polycarbonate products are more expensive as compared to those than have been manufactured from glass or other polymers. It is for this reason that most consumers opt for other materials such as ABS or acrylic. This is mainly common for applications which do not require extra strength.

They are not inherently resistant to abrasion; this is the main reason why they are fitted with anti-scratch coating. Normally, one needs to be cautious, especially, when cleaning the polycarbonate sheets/panels to ensure that they do not leave any scratches on the surface. They are also sensitive to abrasive cleaners such as alkaline cleaning products. It is for this reason that all manufacturers insist on using only those cleaners which have been tested and approved in the laboratories.

The manufacturing process is not environmentally friendly since it requires high processing temperature. There are chances of emissions, which could pollute the environment. In the
manufacturing process, phosgene, which is known for its side effects on both chlorine and human health.

It is important to note that, apart from the cost, the impacts of the other disadvantages of polycarbonate products can be controlled. This is why this product highly recommended in a number of applications where glass could have been used. The polycarbonate manufacturers have been improving the intrinsic properties of polycarbonate and so far, they have managed to improve its ability to resist scratches.

Properties of Polycarbonates
Polycarbonates have unique chemical and physical properties and this has been the main reason why they are preferred to other materials such as polythene, glass, acrylic, etc. All these properties are determined by the nature of bond which exists between the basic elements which make up a polycarbonate sheet. They can be categorized as phenyl and methyl group. Normally, to determine the degree of performance of any polycarbonate product, the two groups must be analyzed independently. It is this structure which is responsible for the amorphous structure of polycarbonates. Of course, this is the technical interpretation of basic properties of polycarbonates. Almost all polycarbonate materials which are available in in market are designed to fulfill the desirable physical and chemical properties which can optimize their performance.

Physical properties of polycarbonates
Some of the most important physical and mechanical properties of polycarbonate sheets/panels include:

*High strength*; their ability to withstand high magnitude of impact has been one of the main reasons as to why this polycarbonates are commonly used in a number of applications such as glazing, greenhouse contraction, hurricane barricades and anti-riot shields. It is this strength which makes them resistant to both fracture and high impact.

All products which have been manufactured from polycarbonates are nearly unbreakable. There are a number of tests which can be conducted to determine the strength of polycarbonate products. One of the most common tests is the compressive strength test where the compressive modulus of polycarbonate is 2.0GPa while the compressive yield strength is 70MPa. The
available polycarbonates are taken through these tests to ensure that they comply with a number of strength tests and applications. Ideally, a polycarbonate with a thickness of 3mm can withstand a force due to a steel ball of about 4kg which has been dropped at about 9.5m high.

*Optical properties:* polycarbonates have aromatic rings which make the molecules to be attracted to each other thus, it prevents the formation of crystalline structure. This has been the main reason for the superlative optical properties of polycarbonate products. Normally, when they are thick, they tend to have a slight yellowish tint. A colorless polycarbonate has a refractive index of about 1.584. This is the main reason why it is used in a number of glazing application and in the construction of greenhouses.

During the production process, polycarbonates can be optimized for high light transmission or the degree of light transmission can be reduced to depending on the nature of the application. This can be done for long optical paths such as in optical fibers.

Tinting or embossing polycarbonates can alter the degree of light transmission. For instance, a transparent polycarbonate with a flat surface will transmit more light than a polycarbonate which is blue in color and has a corrugated surface.

They can be designed to have a light transmission within the range which is near the infrared to about 1.10nm besides the visible light range. Most manufacturers use “natural color to refer” to the color of a polycarbonate material without any correction.

*Electrical and heat resistance:* electrical and thermal transmission take place when there is mobility or vibration between atoms within material surface. Polycarbonates are made up of methyl and phenyl groups which eliminate the mobility of molecules within then polycarbonate structure. This is due to high covalent forces which exist between the molecules of the phenyl group and the adjacent molecules. This results into high thermal resistance and high viscosity of polycarbonate materials. In most cases, a glazing sheet/panel can be manufactured with more than one polycarbonate sheet thereby improving the insulation properties of the overall polycarbonate sheets. Such sheets are referred to as multiwall polycarbonate sheets.
They can maintain rigidity up to a temperature of 140°C and toughness up to a temperature of -20°C. Apparently, the polycarbonate manufacturing companies have been trying to alter the inherent property of polycarbonates with an aim of improving their thermal and electrical resistance properties. They can withstand up to 135°C.

During fire outbreak, they are generally self-extinguishing. They burn at a very slow rate with the flame retardant grades available for a number of industrial and domestic applications. Such polycarbonates are taken through severe flammability tests. A number of polycarbonates grades have a thermal coefficient of expansion of about 65x 10^-6.

*Dimension stability*: the rigidity of the polymer chain due to the existence of both the phenyl and methyl structure has been the main reason for polycarbonate sheet/panel’s dimensional stability. A number of materials with an amorphous structure are dimensionally stable. When polycarbonates are exposed to high stretching forces, they can experience very little elongation. This explains why PC sheets/panels do not rapture even when they subjected to fluctuating temperature.

In a laboratory or a manufacturing set up, there are a number of tests which can be conducted to establish the polycarbonate’s mechanical strength, optical properties, etc. It may involve establishing the polycarbonate’s density, degree of flammability, radiant resistance, Young’s modulus of elasticity, tensile strength, elongation at break, Poisson’s ratio, coefficient of friction, melting temperature, thermal diffusivity, linear expansion, dielectric constant, relative permeability, specific heat capacity, dissipation factor, resistivity, etc.

**Chemical properties of polycarbonates**
The chemical properties of polycarbonate sheets/panels are as essential as the physical and mechanical properties. Normally, the chemical properties play a significant role when choosing a specific grade of polycarbonate material for an industrial application. Some of the most important chemical properties to consider include:
Water absorption; a number of polycarbonate manufacturing companies tend to analyze the degree of water and moisture absorption of all polycarbonate grades. Unlike other materials whose mechanical properties are affected by moisture or water absorption, polycarbonate’s mechanical properties are not affected by water and moisture absorption. This is the main reason why this sheets/panels are used in glazing applications.

Polycarbonates absorb small quantities of water which is less than < 0.6%. When polycarbonates are washed with hot water after a long period of time, they may begin to decompose. The decomposition process reduces the ability of polycarbonate sheets to withstand impact or shock.

Polycarbonates offer limited retraction during molding. Its ability to absorb low moisture/humidity makes it to have a good dimensional stability especially in a humid atmosphere. It should be dried carefully in an oven which has been ventilated or a drier at a temperature of 120° C and 0.1% humidity. During injection molding, it should be subjected to higher pressures of between 800 bars and 1800 bars.

Chemicals; the polycarbonate manufacturers recommend certain cleaning agents which do not affect the basic chemical structure of polycarbonates. Generally, polycarbonate product sheets and products are not attacked by most organic acids and diluted acids. However, it is important to note that polycarbonates are partially soluble in a number of halogenous hydrocarbons. Strong bases like ammonia may attack polycarbonate sheets.

Apart from various solvents, polycarbonate can be affected by light. Generally, polycarbonates are fairly stable in ozone, however, they are not ultraviolet light stable. It is for this reason that all polycarbonates are treated with anti-UV protection since they turn yellow faster.

Test and analysis of polycarbonates
Testing and analyzing various properties of polycarbonates is a sure way of choosing the right polycarbonate grade for a particular task. During the manufacturing process, the mechanical,
optical and thermal properties are tested. Of course, there are very many tests which can be conducted to verify just one property of a polycarbonate sheet. Some of these tests include:

*The impact analysis test:* this one of the ways to determine the ability of a polycarbonate product to withstand a wide range of impacts or forces. Polycarbonates can maintain an outstanding impact within a wide range of temperature (between -40°C and 120°C). Even though polycarbonates are inherently strong, these properties should be verified to avoid chances of failing when they are used in windstorms, snowstorms etc. These tests should assure the use that the material should remain unbreakable in all weather conditions.

Normally, the material to be analyzed is clamped and polyamide balls of varying diameters are fired towards the sheet using a pressurized gun. This test is conducted based on the fact that, under normal conditions, a hailstone with a diameter of about 20mm may reach the surface with terminal velocity of about 21m/s.

*Tensile strength:* polycarbonate manufacturers analyze this property to determine the extent to which a polycarbonate can resist breakage when subjected to tensile strength. The ultimate tensile strength has to be determined. In most cases, the polycarbonate sheet/panel can be pulled apart at a rate of 0.2 inches/minute to 20 inches/minute.

During this test, the tensile elongation and the tensile modulus of elasticity are key factors which should be examined. A polycarbonate material should have an ultimate tensile strength of about 70Mpa; elongation and a tensile modulus of 2.6GPa.

*Thermal properties tests:* by analyzing this property, the end user will be able to select the right polycarbonate grade for a number of electrical installation equipment. During this test and analysis, the following aspects are examined:

1. The glass transition point which can be from the infection point of a refractive index at a temperature between 141 °C and 149 °C. This depends on the molecular weight of the polycarbonate.
2. The melting point; the melting point of most polycarbonates are within the temperature of between 230 °C and 260 °C. This requires about 134J/g of heat.

3. The dispersion temperature; this is where the micro Brownian motion in molecules occur.

4. Thermal conductivity and specific heat; it changes with the temperature of the polycarbonate sheet. This is also analyzed alongside the coefficient of thermal expansion.

5. Deflection temperature; a change in deflection temperature will be determined by the amount of load/stress on the polycarbonate sheet.

During the manufacturing process, all the thermal characteristics which affect the performance of a polycarbonate sheet have to be analyzed. It is for this reason that the polycarbonate manufacturing industries have installed ultramodern thermal testing equipment.

*The light transmission tests;* the degree of light transmission is a major concern considering that polycarbonate sheets are used in glazing applications. Even though polycarbonates can transmit over 90% of light, their surface can be modified to reduce the amount of light passing through the sheet. At times, both refraction and diffusion can be modified to make it suitable for certain applications such as in the construction of greenhouses. Polycarbonates turn yellow if not treated with anti UV light. This is a critical issue which should be tested and analyzed.

During this process, light is classified as UV-B middle UV region, UV-A near ultraviolet region, near infrared region, middle infra-red region and visible light region. Normally, they are designed to be nearly opaque to both UV radiation and far infra-red region. The polycarbonate manufactures use this as a shield to prevent the discoloration of the polycarbonate sheet.

These are some of the most common tests and aspects which are analyzed in the industrial setup. For every application, there are certain properties which play a significant role. It is these properties which be analyzed to optimize the performance of the polycarbonate sheet. For example, in areas which are prone to fire outbreak, these companies will focus more on thermal and frame retarding properties.

**Classification of polycarbonates**

A polycarbonate sheet is formed through condensation polymerization where carbon (C) is bonded with three oxygen (O) atoms. Even though polycarbonates are inherently tough and can
be used for virtually all applications, these properties can be improved to meet certain criteria for specific applications. For example, in situations where insulation is of a priority, they are multi-wall polycarbonates form a perfect choice. Some of the most common types of polycarbonates include:

**Solid polycarbonate**

The available polycarbonate sheets/panels can be classified as either solid or hollow polycarbonate sheets. The hollow polycarbonate sheets air space in between its structure while the solid polycarbonate sheet is compact in design. Generally, the superior polycarbonate sheets are superior to the hollow polycarbonate sheets due to their optimal impact strength and high light transmission. This is the main reason why they are used in applications where urgent light is required such as in greenhouses, lamp boxes, hooting light etc.

![](image)

*These are some of the most common types of solid polycarbonate sheets*

They are available in a number of configurations such as the general purpose (GP), hard coated, light diffuser and anti-fog solid polycarbonate sheets.

**Features of solid polycarbonates**

They have exception light transmission with up to more than 89% light transmission. This is due to the extreme clarity of these sheets. However, the degree of light transmission can be modified
by texturing or tinting its surface. They have a UV protection layer which protects it against the UV light which can cause the surface to turn yellow.

Impact strength; the solid structure of the polycarbonates gives them a high impact strength than most plastics and other glazing materials. Their impact strength is 200 times greater than that of glass and 10 times tougher than that of a toughened glass.

Lightweight; it is one half the weight of glass (considering the same volume). This results into significant costs savings since the overall structure may not require additional reinforcement. In addition to this, it will also save on the freight costs.

Thermal insulation; generally, the solid polycarbonates have a lower thermal conductivity which reduces the loss of thermal heat. Building which have been constructed with these polycarbonates may not require additional air conditioning systems.

Flame resistance; they have a high ignition temperature of about 580°C. The solid polycarbonates have been rated B1.

There are several factors which distinguish the solid polycarbonate sheets from other polycarbonate sheets which are used in glazing application. They include:

1. The construction; these polycarbonates have only one single layer as opposed to two or more layers which is a common scenario with the hollow polycarbonate products.
2. Weight; even though they have a lightweight, they are heavier than the hollow polycarbonate sheets since they do not have air spaces within their structure.
3. Thermal insulation; even though polycarbonate sheets are poor conductors of heat and electricity, the hollow polycarbonate sheets have superior insulation properties. This is because they trap air in between it the layers which act as additional insulator.
4. Price; the solid polycarbonate sheets are more expensive than the hollow polycarbonate sheets. In the solid polycarbonate sheets, more of the polycarbonate resin is required to manufacture a sheet of the same size as the hollow polycarbonate sheets.
5. Sound insulation; the solid polycarbonates offer better sound insulation properties than the hollow polycarbonates sheets. It is for this reason that they are used in applications which require sound proof sheets.

Hollow polycarbonates
This is the second category of polycarbonate sheets. These sheets are manufactured with some spaces in between the layers. One distinct feature about hollow polycarbonate sheets is that they require small quantity of raw materials as compared to the solid sheets.

Examples of hollow polycarbonate sheets

The hollow polycarbonate sheets are also referred to as cellular, channel, multi-wall or structural polycarbonate sheets. They are referred to as cellular polycarbonate sheet due to internal structure of the sheets which as a lot of air spaces. The unique feature of these glazing products include:

1. They have air spaces within the chamber which provide excellent thermal insulation. This is the reason why they are used in glazing applications where heat conservation is of essence.

2. The dividing walls act as supportive structure which provide a strong structural rigidness and flexibility of the polycarbonate sheet.

The hollow polycarbonate sheets are used in applications where transparency and high impact strength are of importance. Their excellent physical strength, mechanical and electric property explain why it is a perfect choice in decoration and building industry. The hollow polycarbonate
sheets possess all the desirable physical and chemical properties of polycarbonate sheets such as high impact strength, light weight, light transmission, UV protection, easy installation, sound insulation, etc. the most common types of hollow polycarbonate sheets include:

1. The twin-wall polycarbonate sheets; these sheets are made up of two polycarbonate sheets with an air space and dividing walls between the walls.
2. The triple wall polycarbonate sheets; they have three polycarbonate sheets which are separated with two layers of air spaces and dividing walls.

There those with four, five or six polycarbonate sheets. The number of walls and air space layers will depend on the desired U-value and R-value. The U-value is used to determine the effectiveness of a material to be used as an insulator while the R-value is the measure of thermal resistance. Ideally, the use of hollow polycarbonate sheets is designed to improve the insulation properties of the polycarbonate sheets.
The internal structure of the hollow polycarbonate sheets vary greatly depending on the magnitude of strength the hollow polycarbonate manufacturer would wish to achieve. Some of the most common internal structure are:

![Diagram of different internal structures]

*These are the most common internal structure viewed from one end*

Apart from the excellent thermal characteristics which the hollow polycarbonate sheets possess, other features include:

1. **Weight;** they are not as heavy as the solid polycarbonate sheets. This reduces the shipping costs. Moreover, the overall structure will not require a lot of reinforcements which also reduces the overall construction cost.
2. **Price;** they are cheaper than the solid polycarbonate sheets since the manufacturing process require less raw materials as compared to the solid polycarbonate sheets.

Choosing the desired hollow polycarbonate sheet is a challenging process, more so, one which should offer optimal light transmission and diffusion. It is for this reason that every polycarbonate sheet comes with their own data sheet where buyers can assess all the physical and mechanical properties. These sheets come in different tints and their surfaces can be modified just like the solid polycarbonate sheets. All sheets should come with a warranty, especially that which protects them from turning yellow prematurely.
Corrugated polycarbonate
The use of corrugated glazing materials is not a nascent technology. This technology has been used to manufacture a number of steel and iron roofing sheets. The corrugated polycarbonate sheets have also gained popularity in the recent past due to the wide range of benefits they offer. They have been designed to meet the specific manufacturing profile of the corrugated iron and steel sheets. Their corrugated nature makes them tough and strong to withstand high impact, especially when they are used in glazing applications.

Like other polycarbonate sheets and products, they possess all the desirable intrinsic features of polycarbonate resin. Their surface and tints can be modified to alter certain features such as light transmission and light diffusion. Some of the most common tints include:

1. The clear corrugated sheets which can transmit 90% of light.
2. The Opal white corrugated sheets which can transmit up to 45% of light.
3. The solar control silver which transmit about 20% of light.
4. Solar gray which can transmit about 35% of light.
5. Hunter gray and red brick which are known for minimal light transmission.

There are the custom made corrugated polycarbonate sheets which are mainly used by those companies and firms which would wish to have a completely unique glazing sheets.

Examples of corrugated polycarbonate sheets
Like other polycarbonate sheets which are used in the industrial and domestic applications, these corrugated sheets are protected against ultra-violet radiation which makes them to offer optimal performance for a very long period of time.
**Advantages of corrugated polycarbonate sheets**

Strength; the main idea of having the corrugated solid and hollow polycarbonate sheets is to add more mechanical and impact strength to these glazing sheets. They are over 200 times stronger than other corrugated plastics. Furthermore, they can retain their mechanical strength within a wide range of temperature of between -40°C to 130°C. This will reduce the maintenance cost and the guarantee safety of the overall structure.

Versatility; the corrugated sheets are rugged, thus, they can be used for virtually all glazing applications such as in skylight and greenhouse construction. They can withstand adverse weather conditions such as hailstorms, fluctuating temperature, etc. They are also flexible which makes the installation process easier and affordable.

Optical clarity; the modern corrugated sheet has been designed with additive which will ensure that the sheets retains its high degree of light transmission throughout its lifetime. That is, for a clear corrugated sheet, it can maintain 90% of light transmission for close to 10 years. This is also a similar scenario when it comes to the opal white corrugated sheets.

Cost; unlike the corrugated iron sheets, the corrugated polycarbonate sheets have a lightweight. This save on the freight costs and the installation costs.

Aesthetic value; the corrugated nature of these sheets is appealing to the eye. This is one of the main reason why they are used to construct stadiums and buildings. The different tints give it a bold appearance.

Apparently, other features such as the multi-wall or textured surfaces are apparently being incorporated in the manufacturing process of corrugated sheet. This will make it appealing to the eye and to serve quite a number of domestic and industrial applications.
Polycarbonate products
Polycarbonate is a versatile engineering material which is used to manufacture a number of domestic and engineer products. Some of the most common products include:

Polycarbonate sheets and panels: the polycarbonate sheets are panels are available in different configurations. They have excellent mechanical, thermal, optical and chemical properties. It is for this reason that they used in glazing applications such as in the construction of green houses.

![A polycarbonate sheet greenhouse](image)

The polycarbonate sheets are available in different configurations such as the multiwall, embossed, textured and corrugated sheets. Each sheet has unique advantages and disadvantages. For instance, the multiwall polycarbonate sheets are known for good thermal insulators.

Generally, these sheets are used to make a number of roofing materials in the modern architectural designs.
A corrugated polycarbonate sheet used as roofing material

**Bullet proof windscreens:** the bullet proof windscreens and windows is yet another common polycarbonate product. This has been due to their unbeatable strength and light weight. They are popularly used in banks as security measures to prevent attacks. The bullet proof windscreens are 30 times stronger than acrylic and 250 times stronger than glass. These windscreens are virtually unbreakable and they do not break. This eliminates chances of replacing the windscreen.

**Protective devices:** due to its strength, polycarbonates are used to manufacture a number of protective gadgets. One of the most common gadget are the anti-riot shield and helmet which are commonly used by law enforcers. They can with stand all manner of impacts without breaking.
The images of anti-riot shields and helmets

Automotive industry; polycarbonates are commonly used in the automotive industry to manufacture a number of products. Companies like Jeep are using polycarbonate sheets to manufacture windscreens for their vehicles. They can remain intact even when they are driven in rough terrains.

Jeep with a polycarbonate windscreen.

A number of vehicles are fitted with polycarbonate headlamps besides having the interior sections of the car designed using polycarbonate products.

Swimming pool enclosures; polycarbonates can be used as swimming pool enclosures. This is due to their dimensional stability. Polycarbonates absorb very little amount of moisture. Moreover, this moisture do not affect their mechanical and physical properties of polycarbonates.
Polycarbonate films; the polycarbonate films are used in a number of applications such as in electronic, auto, screen printing and graphics industry. They are also used in graphic overlay, LCD display and nameplate printing. These materials come in different surface finish such as textured and clear glass finish.

Food containers and cans; polycarbonates are used to make a number of food containers and cans. Apparently, there are no side effects of Bisphenol A which have been identified. They are used to make a number of household products.

Ideally, polycarbonates are used to make a number of plastic products and glazing applications. Even though polycarbonate is expensive, its intrinsic features are worth a long term investment.
This is evident from the fact that most manufacturer offer 10 years warranty for most of their polycarbonate products.

**Polycarbonate grades**

Due to the varying application requirements, there is need to manufacture different polycarbonate grades. Certain properties such as the degree of light transmission and the overall strength of the polycarbonate can be manipulated using different grades of tints. A number of polycarbonate manufacturing companies use this criteria to differentiate their products and those that exist in the market.

Despite all these modifications, a good polycarbonate sheet should meet the following criteria:

1. Possess good creep resistance
2. Remain effective within a wide range of temperature limits
3. Have good dimensional stability
4. Exhibit good electrical and thermal insulation
5. Maintain self-extinguishing properties.
6. Good heat resistance with higher melting point

Normally, the polycarbonates become sensitive to hydrolysis at very high temperature, thus, there should be additional venting equipment to pre dry the polycarbonates before they are taken through any heat processing. This eliminates the formation of blemishes or bubbles on finished parts.

**Forming polycarbonates**

Polycarbonates are popular engineering thermoplastic with a high-molecular weight and amorphous in nature. They are distinguishable from other engineering thermoplastics due to the fact that they can be formed into different shapes. They are available in different grades such as flame inhibition, bullet resistant, sign grade, UV enhanced and general purpose polycarbonates.

Polycarbonates have good thermoforming characteristics thus, they can be machined or fabricated depending on the recommended techniques. At times, they can be taken through a
number of secondary operations to ensure that the final product is of high quality. During the fabrication process, a number of specialized tools are used to ensure that end product meets the desired characteristics.

There are a number of techniques which are used to shape polycarbonates into the desired shapes and configurations. Over years, thermoforming has proved to be one of the most efficient and cost effective way of shaping polycarbonates. This is because it gives the designer an opportunity to develop complex shapes within the limited resources at the polycarbonate manufactures disposal. The modern thermoforming process guarantees low cost tooling, fast turnaround while still ensuring large part production. For this reason, engineers can produce polycarbonate parts with enhanced design opportunities. There are very many design options which are available in the market thus, choosing the right design technique is the very first step of ensuring accurate and desirable polycarbonate parts are produced. Thermoforming polycarbonate involves the following key steps:

*Pre-drying*; even though polycarbonates absorb low quantity of moisture, most resins are intrinsically hygroscopic. Before the thermoforming process begins, it should be dried to remove any moisture which may build up within the moisture during the manufacturing process. This moisture may cause bubbling and other reduced in the property performance. Polycarbonates can be pre-dried using hot air circulating an oven at a temperature of about 125°C.

Normally, the polycarbonate sheets come in a protective masking. After the protective masking has been removed, the polycarbonate sheet should be held vertically in the drying oven. The pre-drying time will depend on the thickness of the polycarbonate sheet. For example, a polycarbonate with a thickness of 0.375mm can be dried for 0.15hrs while that with 3.00mm can be dried for 4hrs.

*Thermoforming technique;* thermoforming involve three main steps which involve heating the polycarbonate to a forming temperature, shaping the polycarbonate and cooling the polycarbonate. There are very many forming techniques which can be classified as:
1. Those that require heating for the polycarbonate to conform to the desired shape. This can be a negative or a positive mold.

2. There are the pressure or the vacuum forming techniques where the polycarbonate is forced to conform to the desired shape by subjecting it to a vacuum or pressure.

Heating polycarbonates; a controlled heat source should be used with the heating taking place uniformly. The heating process will determine the quality of the end product. In most cases, the sandwiched type of heaters are commonly used in polycarbonate thermoforming. Some of the most common types of heaters include the infra-red, quartz or ceramics. The heating process will depend on the types of part to be formed, forming technique and the thickness of the polycarbonate sheet. The heating process should be guided by the following key principles:

1. When polycarbonates are formed at low temperature, there will be minimum spot thinning and a better hot strength. It is mainly designed for shorter cycle time.
2. At higher temperature, low internal stresses will be realized, however, this may increase the rate of mold shrinkage. This may cause non uniformity in the thickness of polycarbonate being formed.

Cooling; this is an important process in the polycarbonate thermoforming. There are a number of factors which determine the cooling technique. These include design geometry, mould material, mould temperature, thickness of the part and forming temperature. For polycarbonate grades with a high distortion temperature, water cooling or forced cooling air may be used.

The polycarbonate product design; this is yet another factor which affects the thermoforming process. Product design may focus on the following key categories: aesthetics, economics, function and manufacturing. Even though the first three are mainly determined on the actual product, the manufacturing process as a function of the polycarbonate product design may have some limitations.

Some of the main factors which affect the manufacturing process include:
1. Product geometry; it is mainly used to determine the degree of stretching. It is from this that the ratio of surface area of the thermoformed polycarbonate to that of the available polycarbonate sheet can be determined.

2. The radii; it applies in either negative or positive thermoforming.

3. Draft angles; this is a common feature whenever the manufacture wants to deal with the possibility of polycarbonate shrinking during cooling. All surfaces should have adequate draft angles.

4. Undercuts; they become a major concern in vacuum forming however, such molds have a complex design.

Bending polycarbonates

This is a common process which is used in polycarbonate fabrication. The bending techniques which are used in most polycarbonate manufacturing process include:

*Hot line bending*; this process involves bending polycarbonate sheets using heat. This makes it easier to bend sheets with thicker sheets to form desired acute angles. The PC sheet is heated along the line of the bend using the radiant heater. The polycarbonate can be heated from both sides depending on the polycarbonate grade. In case of a single side heating, the sheet may be turned severally for it to be heated effectively. During the hot bending process, the polycarbonate can be heated without removing the protective masking.

In most cases, when the heaters have attained a temperature between 155°C and 165°C, the heaters should be switched off as the sheet is bent to the required angle. When precision heating or high volume production is required, sophisticated machines with temperature controlled heaters are commonly used.
An illustration of hot bending polycarbonate sheets

It is important to note that, in situations where localized heating systems are used in the hot line bending, the expansion characteristics could be unpredictable. It is important to begin the process by bending prototypes to establish the feasibility of the bending process. This is mainly conducted to ensure that the intrinsic properties of the polycarbonates are not altered.

*Cold curving*: the bending radius depends on the thickness of the polycarbonate sheet. In this process, the curved sheet is clamped and a slight bending stress is applied across the polycarbonate sheet. The magnitude of stress should not exceed the recommended force which may alter the performance characteristics of the polycarbonate sheet. This technique may not be recommended for all polycarbonate grades. When polycarbonate sheets are exposed to a certain magnitude of stress, they may be susceptible to certain chemicals. As a rule the bending radius should be a minimum of 100 times the thickness of the polycarbonate sheet. For instance, the bending radius of a polycarbonate panel with a thickness of about 2.0mm can be 350mm.

*Cold line bending*: it is a suitable technique for low temperature and ductile polycarbonates. This process involves a permanent plastic deformation. The nature of the bent surface will be determined by the thickness of the sheet, angle of strain bending and tool. The cold bending process should meet the following criteria:

1. The tools should have a sharp edge but must not damage the sheet
2. After the old bending process, the sheet should be given enough relaxation temperature of between 1 and 2 days.
3. The polycarbonate should not be forced into a desired position.
4. The cold bending process should be conducted within a short period of time to obtain optimal result.
5. When bending the textured polycarbonate sheets, the textured surface must be in the compression
6. Over bending the sheet is recommended to obtain the desired angle since stress relaxation may occur.
7. The colored sheets may show variation in color along the bend.

Types of bonding and finishing
Bonding is an important process in the polycarbonate installation process. The choice of bonding and fastening materials will depend on the nature of the application.

Fastening; aluminum rivets are commonly used to fasten polycarbonates. In this process, the holes should be oversized with washers placed between the screws to distribute stress evenly on the surface of the polycarbonate sheet. The choice of these materials should be based on the difference in the coefficient of expansion of dissimilar metals.

Bonding solvents; there are a number of polycarbonate bonding solvents which are used in this industry. Even though bonding solvents are effective and efficient, they can reduce the strength of polycarbonate sheets significantly. All manufacturers do outline the recommended procedures when using solvent bonding. During this process all edges should be clean, surfaces smooth and an even pressure should be applied on all surfaces. These bonding solvents may cause the polycarbonate surface to whiten. To reduce this phenomenon:

1. The bonding process should take place in a climate controlled region which has low humidity.
2. In certain scenarios, about 10% of glacial acid could reduce whitening.
3. Whitening can be reduced by thickening the solvent with polycarbonate resin or saw dust.

Finishing; this is process aims at giving polycarbonate products a unique appearance. This process is commonly used by companies which would wish to print unique logos on their products. Some of the most common finishing operations include sanding, joint planning, solvent polishing, hot stamping and screen printing.
Application of polycarbonates

Due to the superb mechanical, optical and thermal properties, polycarbonates are used in a number of applications. Even though the initial investment cost is high, they can last for more than ten years when they are still in good shape with all its mechanical, optical and thermal properties still intact. They are a perfect choice for a long term investment. This material is commonly used in glazing applications especially the corrugated and the multi-wall polycarbonate panels.

Glazing applications

These sheets have replaced toughened glass, polythene membrane and glass in a number of glazing applications such as in agriculture, industry and public building. Of course, this has been from the fact that it combines UV protection, high impact strength, anti-drop, light weight and flame-resistant properties.

The polycarbonate manufacturers have been improving different properties of polycarbonate sheets to make them suitable for virtually all environments. For example, the frost and embossed polycarbonate sheets have gained popularity in the glazing industry due to their additional strength. Furthermore, the textured polycarbonate sheets encourage light diffusion which can optimized production in the greenhouse.

The choice between the solid and the hollow polycarbonate sheet will depend on the specific objective the glazing sheet should achieve. The main consideration in the degree of thermal
insulation. The hollow polycarbonate sheets have an enhanced thermal insulation properties. This is the main reason why the multi-wall polycarbonate sheets are used in most glazing applications. This is because it traps air in between the spaces which contributes to its excellent thermal barrier.

There are a number of factors which should be considered when using polycarbonates as glazing sheets. These include:

*The installation guideline*; this is a crucial process when you’re opting to use polycarbonates as glazing applications. All manufacturers have clear procedures on how the installation process should take place. The installation process involves choosing the recommended sealants, washers and fasteners. The rate of expansion is one factor which should be considered in the glazing process since installation process involves the use of dissimilar products. In the data sheet, the manufacturer will list all the recommended sealants, gaskets and tapes which should be used with a specific product.

A number of polycarbonate glazing sheets are installed using either dry or wet glazing systems where they can be used as for over glazing or double glazing application. Of course, maintaining the recommended separation between the glazing sheets will prevent touching during high heat or high humidity conditions. The important installation procedure include:

1. Only the recommended sealants should be used to avoid incompatibility problems. At times, the glazing sheet could be exposed heavy load which requires low modulus and high performance elastomers.
2. A proper edge engagement and expansion allowance should be chosen carefully. Only the recommended cutting tools should be used. These tools will ensure that the surface is smooth and free from any notches or chips.
3. Both the sash and prime should be clean. In case, the process involves replacing the old glazing sheets, the old projections and sealants should be removed.

*The wind load performance*; polycarbonates which are used as glazing applications are exposed to a hostile environment such as hailstones, fluctuating temperature conditions and high speed wind.
Most of these factors are unpredictable and it is for this reason that factors such as wind performance characteristics should be analyzed.

*Expansion allowance:* despite the fact that polycarbonates are dimensionally stable, they may expand and it is for this reason that manufacturers indicate the recommended expansion allowances.

*Maintenance process:* cleaning is the most basic maintenance procedure which should be conducted periodically to ensure that the polycarbonate glazing sheet remains in good condition. The manufacturer will always recommended those cleaners which are compatible with the polycarbonate sheets. Use a soft cloth since polycarbonate is susceptible to scratches. It is for this reason that the use of abrasive cleaners are never recommended for the cleaning process.

In addition to these, the technical information about the polycarbonate glazing sheet is an important document. It is through this that the end user determines the type of glazing sheet to use. The installation process could be easy if one is a professional, however, hiring a professional company could be only option for those who are using polycarbonates for the first time.

**Product selection process**
Product selection is a challenging process and in most cases and it is nearly impossible to come by a product which is 100% perfect. All engineering product have their unique advantages and disadvantages which every user should be able to scrutinize. One key tool in the product selection process is the specific application requirements. The polycarbonate grade should fulfill all the needs of the end user. It is for this reason that there exist the corrugated, embossed, prismatic, solid and multiwall polycarbonate sheets. The product data sheet is also a crucial tool in the product selection process. All physical and chemical properties of all polycarbonates are indicated in the product data sheet. Some of the key issues to consider in the product selection process include:

*Product description:* this is the general overview of the polycarbonate sheet, whether it is embossed, hollow, solid or corrugated sheet. The key issue to consider include the dimension of
the product and the type of tint. A number of polycarbonate manufacturing companies produce a
number of standard products, however, there are the custom made polycarbonates with specific
structures. The custom made products are slightly expensive than the standard products, but,
they play a significant role when it comes to product differentiation.

**Thermal properties;** the thermal expansion and service temperature are crucial features that one
should consider when choosing a polycarbonate sheet. The insulation value should be analyzed,
more so, with the multiwall polycarbonate sheets.

**Optical properties;** what is the solar heat gain coefficient of the polycarbonate sheet of choice? The
polycarbonate sheet should meet the desired optical criteria especially when it should be used as
a glazing material. For instance, polycarbonate sheets which are used in the greenhouse
construction should diffuse light while eliminating chances of burning effect.

**Technical information;** there are certain information that the ordinary polycarbonate user may not
comprehend, however, they are essential when determining the overall performance of a glazing
sheet. The chemical resistance, fire performance properties, acoustic properties, UV protection,
cold bending and impact resistance. It is these factors which determine whether a polycarbonate
sheet is suitable for particular task.

**The general user guide information;** the sheet may possess all the desired physical and chemical
properties, however, ignoring the user guide information will reduce the lifespan of the sheet
significantly. These may include the recommended storage procedures, cleaning, drilling and
cutting procedures.

**Cost;** as compared to other engineering sheets, polycarbonate sheets are relatively expensive, but,
they are durable. This sheets are recommended for individuals who would wish to realize long-
term cost saving.

**Mode of purchase;** buying polycarbonate products is slightly cheaper than buying the products in
small quantity. It is the same feature which is associated with making purchase in bulk.

Ideally, all these factors form an important technical information requirement which every
polycarbonate sheet user should consider at all cost. It is for this reason that all polycarbonate
users are expected to buy the polycarbonate products from a company which meets the following criteria:

![Image of customer satisfaction factors]

**Important features of a polycarbonate sheet supplier**

*Experienced are reputable*; there are very many polycarbonate manufacturing companies, however, only a few can produce reliable and quality products which can be trusted. Going by the consumer reviews and the history of the company in the industry, it is possible to get quality products which can be trusted.

*Warranty*; a number of polycarbonate sheets come with a warranty. The period of the warranty may vary depending on the quality of the product. A warranty is a clear indication that the company trust the products they are supplying in the market. In the polycarbonate industry, the UV protection should be covered in the warranty.

*Certification*; in all manufacturing process, quality control is a crucial process. This is the only way a company can produce products which conform to the required global standards. A company which is not regulated and are not certified could be producing substandard sheets. Thus, it is advisable to avoid such companies at all cost. The chances that such products may fail is very common.

*Shipping process*; does the company has a reliable shipping procedure? How much does it cost? Purchasing a product from an online store could be a simple task, however, the delivery process can be discouraging especially if you have to wait for months before receiving the final product.
Customer-client relationship: how does the sales representative treat you? Are they able to respond to all your concerns within the scheduled time? Deal with those companies which can address all your concerns within the shortest time possible.

Polycarbonates are essential engineering materials which are used in a number of applications due to the superior properties that they possess. It a reliable plastic which is commonly used in the construction industry. Before purchasing polycarbonates, it is important to analyze all the basic factors which determine the overall performance and the durability of the polycarbonate sheet.

In summary, polycarbonate is a material which combines desired thermal, mechanical and optical properties. It has a unique balance of high heat resistance, dimension stability, toughness, optical clarity and excellent electrical resistance. It is for this reason that it is used in a number of applications such as in skylight construction, greenhouses construction, canopies, digital media, automobiles, sports safety, medical devices and conservatories. To fulfill these application requirements, they are available in different grades such as the corrugated, textured and multi-wall polycarbonate sheets. For optimal performance, the polycarbonate selection process is a crucial process where users need to analyze every single aspect in the product data sheet. It can be used as a perfect substitute for a number of engineering materials.
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