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USING OF POLYETHYLENE TEREPHTHALATE (PET) PANELS IN PRODUCT DESIGN: A SAFE DISPOSAL FOR PLASTIC WASTE

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ABSTRACT. The world has known plastic as an unparalleled material that can help transform our lives for the better and as an alternative for many of the natural raw materials available in the environment targeting to preserve various environmental resources and raw materials. In 1973, Du Pont Chemical Company introduced the first plastic bottle made from PET. The study deals with the importance of polyethylene terephthalate panels (PET) in the field of product design and the way of using and employing them for better product characteristics and properties, in order to ensure safe disposal of plastic waste and preserve our environment. As resulted, PET panels are considered one of the important materials in the field of product design that can be used for products improvement especially in terms of endurance; durability, thermal insulation, sound insulation, transparency, and aesthetic appearance. PET panels also play an important role in reducing product costs and ensuring safe disposal of some plastic waste. To conclude, though and through the findings, PET Panels are suggested to be used in the field of product design as an alternative for many of the currently used materials for their cheap price and eco-friendly impact to ensure improving of the properties of products and achieving a safe disposal of plastic waste..

KEYWORDS: Plastic waste; Plastic & micro-plastic pollution; Polyethylene terephthalate panels

ABBREVIATIONS:

PET	Polyethylene Terephthalate
PET-G	Polyethylene terephthalate glycol

1. INTRODUCTION

Plastic is an organic plastic material. Over the years, man has worked hard to imitate products similar to sugar, fat, and starch [13] He was able to produce the first small unit called a monomer, which turns into what is called a polymer when it is multiplied a number of times Polymers include dyes, sponge plastics, and motor oils, not to mention plastic products for daily use, such as plastic bags, mineral water bottles, packaging containers, etc. The world became aware of plastic for the first time about a century ago or a little more than that, as it is an unparalleled material that can help us transform our lives for the better and that can replace the excessive and increasing cutting of trees to obtain their wood. In 1973, Du Pont Chemical Company introduced the first plastic bottle made from PET. [17] With the passage of time and with the increasing use of plastic and its entry into most areas of life, with which dispensing with plastic products has become unattainable, a major crisis appears on the horizon, which is how to dispose of plastic after the end of its use and the dangers caused by waste and plastic waste. On the environment, the individual, and society, and the term plastic pollution and micro-plastic pollution appeared.The Mediterranean Sea is considered one of the most polluted bodies of water with plastic waste in the world. According to a report issued by the World Wildlife Fund (WWF) in 2018, Egypt is one of the most countries responsible for plastic pollution in the Mediterranean Basin, with about 77 tons per day [9]. France is responsible for 66 tons, Spain 126 tons, Italy 90 tons, while Turkey is responsible for 144 tons.

Other studies indicated that Egypt is responsible for about 30% of the plastic waste leaking into the waters of the Mediterranean, while Turkey bears responsibility for about 17%, while Italy bears responsibility for about 11%, while Algeria bears responsibility for only about 6% [15].

One of the studies conducted on 20 countries in the region regarding the amounts of plastic waste generated by each country relative to the number of individuals, indicated that Egypt occupies the fourteenth place among those countries, as it generates about 700 grams per day per person, of which approximately half (about 1.9 tons per day) of plastic bags and packaging materials, according to data issued by the Ministry of the Environment, while the amount of plastic waste generated daily from Morocco, for example, does not exceed only about 50 grams per person, the increasing use of PET products has led to a global crisis in waste management, as improper disposal of products has caused significant environmental damage [12] which represents a major crisis and a serious threat to The health of both the individual, society and the surrounding environment, which can be considered as a research problem, which is how to safely dispose of some types of plastic, namely PET panels, through the field of product design with the aim of improving their properties in addition to preserving the environment.

2. BACKGROUND

With the increasing use of plastic and its indulgence in most areas of life, the process of dispensing with plastic products has become impossible. However, major crisis has occurred as a result of how to dispose after use, in addition to the threats caused by waste and plastic waste, and the term plastic pollution and micro-plastic pollution has emerged. The increasing use of PET products has also led to global crisis in waste management, as improper disposal of products causes significant environmental damage, which represents a major crisis and a serious threat to the health of the individual, society, and the surrounding environment. Therefore, this research is concerned with focusing on how to safely dispose of waste PET products by identifying some types of PET sheets, their various properties, and methods of forming them, in addition to conducting some tests on samples of them to practically verify some of these properties and implementing some practical applications using these samples to define how to make use and employ them especially in the field of product design with the aim of improving the properties of products, as designing of products and selecting their suitable and appropriate constructing materials is considered one of the basic operations in the design and development process.

2.1. RESEARCH PROBLEM-

How to safely get rid of plastic waste, and invest it especially in the field of product design with the aim of improving the product properties and preserve addition to preserving the environment?

2.2. RESEARCH OBJECTIVE:

The research aims to:

- Study the importance of polyethylene terephthalate panels in the field of product design.
- Show how to use and employ them in the field of product design.
- Ensure safe disposal of plastic waste and preserving the environment.

2.3. RESEARCH IMPORTANCE:

- ***Environmental field:*** Safe disposal of some plastic waste, as well as preserving our environment.
- ***Scientific field:*** Providing researchers and designers in the field of product design with the characteristics, importance, and how to employ polyethylene terephthalate panels in a wide range of products.

2.4. RESEARCH METHODOLOGY:

- Descriptive analytical method: By studying the properties, types and applications of polyethylene terephthalate panels.
- Experimental method: By conducting some laboratory tests on some polyethylene terephthalate panels samples in order to verify some of their properties and how to make use of the test samples in the design and formation of some products.

2.5. RESEARCH HYPOTHESIS:

By defining the properties and types, polyethylene terephthalate panels can be used and employed in the field of product design, for the reduction of plastic waste and environment preservation the environment.

2.6. PLASTIC WASTE:

Plastic waste is considered one of the major environmental challenges we face in the modern era, due to its negative impact on humans and the environment. Plastic waste is a type of solid waste that consists of spent or damaged plastic products such as bottles, containers, cans, and many plastic products that have not been reused or recycled properly. One of the most important disadvantages

of this waste is its slow decomposition, as the decomposition of natural plastic requires very long periods of time, extending for centuries, before it decomposes completely, which leads to the accumulation of plastic waste in the environment and the pollution of seas and oceans. It also affects natural resources, as the production of plastic requires more oil and other natural resources. Which leads to the depletion of natural resources and an increase in carbon emissions that cause global warming? One of its most important effects is also visual pollution, as the large accumulation of plastic waste causes visual pollution, as it affects the natural and aesthetic views of the environment. Therefore, we must address this problem and adopt strategies to reduce the use of plastic, promote recycling, and develop biological and sustainable alternatives to traditional plastic.

2.7. PLASTIC AND MICRO-PLASTIC POLLUTION:

Plastic pollution could be defined as the process of accumulation of plastic within the environment, which negatively affects the health of the individual, society, the environment, marine life, and various organisms. As for the term micro-plastic pollution, it means the process of division and fragmentation of plastic waste into micro-plastic, which are particles whose size ranges from 2 to 5 mm, or macro-plastic, which are particles whose size may reach about 20 mm, as these small particles seep into the soil or bodies of water. Different types of plastic are absorbed by plant roots, ingested by fish, or stuck to the bodies of coral reefs, oysters, and corals, which ultimately leads to this plastic pollution reaching our food and from there to our bodies, causing many diseases and major health problems that may lead to death [9]. A report issued by the United Nations program in 2019 estimated that about 368 metric tons of plastic were produced around the world during the year 2019 only, with about 8 million tons of plastic waste reaching the marine areas annually. It takes about 100 years for a single plastic bottle to completely decompose, and during that period it travels around the world, traveling and crossing distances due to waves and water currents, leaving many small plastic particles resulting from its partial decomposition everywhere.

2.8. PET PANELS:

PET panels, also known as PET panels or PETG panels, refers to panels made of polyethylene terephthalate (PET) or polyethylene terephthalate glycol (PETG). It is a thermoplastic polymer that can withstand temperatures up to 80 degrees Celsius without losing its mechanical properties, which makes it an excellent material for applications that require resistance to high temperatures. It also has high tensile strength, high dimensional stability, and is resistant to chemicals such as acids, bases, and solvents, so it is used on Widely used in various industries, polyethylene is considered an excellent base for the manufacture of plastic sheets, garbage containers and all kinds of household items due to its good properties [11]. Mechanical recycling processes are used [12] or the treatment of plastic materials such as polyethylene terephthalate and return them into resinous granules without affecting the polymer chain in order to prevent any deterioration that may occur to it during recycling, as well as to maintain its quality [12]. The previously mentioned resinous granules are considered the basic component. It is used in the production of fiberboard panels or tiles with a length of about 2400 mm and a width of about 1220 mm, with thicknesses ranging between 5-22 mm and a wide variety of colors (about 40 different colors) [15]. These panels are characterized by being lightweight, environmentally friendly, and absorbing very little moisture, in addition to being a good insulator of both sound and heat.

2.9. PROPERTIES OF PET PANELS:

PET panels are characterized by many mechanical, thermal, chemical and natural properties are as follows [1]:

- ***Light weight:*** which makes it suitable for use in designing products that need light materials to reduce the overall weight of the product and improve the efficiency of transportation and distribution.
- ***Durability, hardness, and stress tolerance:*** making it resistant to breakage, corrosion, chemical corrosion, and high pressures. These properties make them ideal for use in products that are exposed to challenging conditions or require high durability, such as industrial parts, equipment and engineering applications.
- ***Easy to form:*** It can be easily formed into different shapes according to design requirements. It can be cut, bent, perforated and shaped by heat, as it is formed at a temperature ranging from 230 to 260 degrees Celsius, in addition to being able to withstand high pressures, which provides

great flexibility in the design process and allows the manufacture of various products.

- ***Heat resistance (thermal insulation):*** That makes it suitable for use in applications that are exposed to high temperatures, such as moving parts in cars or electronic devices.
- ***Moisture resistant:*** making it suitable for use in humid environments or in products exposed to water or moisture, such as food packaging, plastic bottles and electronic devices.
- ***Light reflective:*** These panels are able to reflect and redirect light and enhance illumination.
- ***Soundproof:*** It is characterized by its good sound insulation, which makes it an ideal material that can be used in theatres, auditoriums, libraries, conference rooms, and recording studios [1].
- ***Scratch resistance:*** *These panels contain a protective layer that helps them resist scratching.*
- ***It can be produced in curved shapes***, which provides great flexibility in designing industrial products according to design requirements.
- ***It can be reinforced with other materials***, such as metals or fiberglass, to improve its durability, sustainability, and ability to withstand heavy loads.
- ***It can be easily colored*** during the production process.
- ***Safe during production***, formation and use, as no harmful substances are produced during these processes compared to glass wool insulation or mineral rock wool insulation.
- ***It is available in several types and shapes***, including solid, transparent, colored, and printed panels.
- ***A material available in many shapes***, sizes and thicknesses according to design requirements and at a low cost.
- ***It can be recycled after use***, which makes it an environmentally friendly material.

2.10. TYPES OF PET

2.10.1. Polyethylene terephthalate glycol (PET-G) panels:

A transparent, durable thermoplastic material, as shown in Fig. 1, PET-G is a relatively hydrophobic polymer and belongs to the polyester family. It is a variation of PET (polyethylene terephthalate) that has been modified by adding glycol, enhancing its flexibility and impact resistance. PETG is known for its excellent clarity, durability, and ease of processing but has outstanding impact resistance and clarity. It is also resistant to many chemicals, including acids and alkalis, which makes it suitable for various industrial applications. It is considered a safe material for packaging food and drinks. It can also be used in making signs, displays and protective screens thanks to its resistance to shocks. Motorcycle screens, where degrees of resistance to radiation are available. UV PETG for outdoor applications that require protection against the effects of weather. They are often used in applications that require high transparency and rigidity, such as display cases, signage, protective barriers, prototypes, orthotics, and prosthetics.

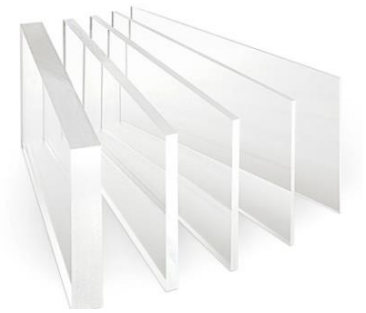

Fig. 1. Shows Polyethylene terephthalate glycol (PET-G) panels

2.10.2. PET Foam Panels:

In recent years, there has been significant interest in polyethylene terephthalate (PET) foam as a base material for structural applications, mainly due to the balance between its mechanical properties and cost (Science Research). It is a type of composite panel consisting of two layers of PET insulated by a polymer foam layer. The polymer usually used is polyurethane (PU) or polyethylene (PE). These panels are formed by a manufacturing process that includes heating, shaping and cooling. These panels are coated from the outside using several materials that are fixed to the two outer layers using adhesive materials. Among the most important materials used in the two outer layers is fiberglass, aluminum, metal, wood, or any other materials according to the design requirements, as shown in Fig. 2. It is a lightweight material and provides good thermal insulation properties. They are commonly used in applications requiring structural strength and insulation, such as building facades, roofing, and insulated panel construction [16].

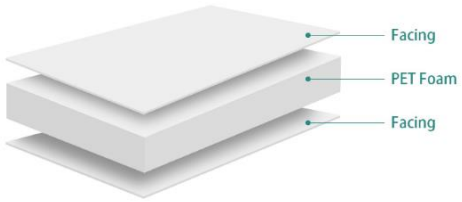

Fig. 2. Shows PET Foam Panels

Composite insulated panels have been widely applied in civil engineering, construction, marine and aerospace due to their high cost-effectiveness and structure efficiency. In recent years, there has been significant interest in polyethylene terephthalate (PET) foam as a base material for structural applications, mainly due to the balance between its mechanical properties and cost. Another advantage of this foam is its sustainability. In fact, they are recyclable and are mostly produced from recycled materials.

2.10.3. Acoustic Panels:

PET Acoustic Panels, also known as PET felt panels, are sound-absorbing panels made from recycled polyester materials, specifically PET (polyethylene terephthalate) panels, which helps reduce waste and promote sustainability. These panels are designed to absorb sound waves to reduce noise, control echo, and improve acoustic conditions in different spaces. Although PET acoustic panels can improve sound absorption, their effectiveness depends on factors such as panel thickness, density, surface area coverage, and the specific acoustic properties of the room. These panels are considered environmentally friendly and safe, as no harmful substances are produced compared to glass wool insulation or mineral rock wool insulation. It is also characterized by its durability and resistance to corrosion. It is used in theatres, halls, recording studios and other spaces where sound control is important. It is available in different designs, sizes and colors as shown in the Fig. 3.

Fig. 3. Shows PET Acoustic Panels

2.10.4. Recycled PET panels:

Also known as PETE panels as shown in the Fig. 4, they are made from recycled polyethylene terephthalate (PET) plastic such as post-consumer plastic bottles. They achieve environmental sustainability by reducing the amount of plastic waste that ends up in landfills or oceans. Recycled PET panels can be used in many applications, including wall cladding, partitions, furniture and decorative elements [19].

Fig. 4. shows Recycled PET panels

2.11. APPLICATIONS OF POLYETHYLENE TEREPHTHALATE (PET) PANELS IN THE FIELD OF PRODUCT DESIGN:

Polyethylene terephthalate panels are considered one of the most important materials in the field of industrial product design that have been used in many industrial products, such as:

Using of PET foam panels in the bodies of refrigeration trucks, as shown in Fig. 5, as having the ability to take care of the truck contents and provide thermal insulation, light weight, and durability [12].

Fig. 5. Shows Use of PET foam boards in refrigerator truck bodies

PET panels, films and foams are used in the automotive industry, as PET foams are used in the manufacture of car seats, as shown in Fig. 6. PET films are used to cover glass windows to reduce breakage in the event of accidents, and to protect headlights and taillights from scratches and ultraviolet rays. PET foams are used as a lightweight and durable material for vehicle

interiors such as door panels, instrument panels and roof linings [6, 10].

Fig. 6. Shows the use of PET panels, films and foams in automotive industry

PET foam panels are also used in the floors and sides of yachts as a filling material that insulates sound, heat, and humidity, as shown in Fig. 7 [12].

Fig. 7. Shows PET foam panels in floors and sides of marine boats

PET foam panels are also used in the floors, sides, and ceiling of high-speed trains as a filling material that insulates sound, heat, and moisture, as shown in Fig. 8 [12].

Fig. 8. Shows PET foam panels in floors, sides, and ceiling of high-speed trains

Fig. 9 shows a table top valet for personal effects molded from recycled PET felt [14].

Fig. 9. Shows a table top valet for personal effects molded from recycled PET felt

Fig. 10 shows some designs for using high-density, sound-proof PET panels in offices and open places to reduce noise during work and achieve privacy for each individual [3]

Fig. 10. Shows using high-density acoustic PET panels as a soundproof noise reducer in open-plan offices.

Fig. 11 also shows the use of PET panels in restaurants seats to provide privacy and reduce noise [4].

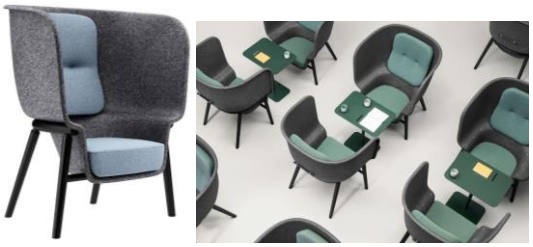

Fig. 11. Shows the use of PET panels in restaurants seats to provide privacy and reduce noise.

Fig. 12 shows the use of PET panels in lining walls in schools and clubs to meet aesthetic needs and reduce finishing costs [11].

Fig. 12. shows the use of PET panels in wall cladding of schools and clubs

3. METHODS

3.1. LABORATORY TESTS:

The researchers conducted some laboratory tests on samples of PET panels at the laboratories of the National Institute for Standardization (NIS) in Cairo to verify the properties of this material for applying in the field of product design. A sample of the material was used with the following specifications: Weight of a sample of the material measuring 5 cm * 5 cm and thickness of about 8 mm is between 3.22 to 3.53 grams according to the test results of ASTM D3776 / D3776M – 09a Standard Methods for Mass Per Unit Area (Weight) of Fabric (Fig. 13), and its density is about 0.1767 g/cm3, according to the results of the EN ISO 1973 test: 2021 Textile fiber of linear density-Graphic method and vibroscope method (Fig. 14).

*Fig. 13. the process of indicating the weight of a 5 cm * 5 cm PET Sample*

EN ISO 1973:2021 Textile fiber of linear density – Gravimetric method and vibroscope method

مساحة العينة/ 0.8*5*5

العينة	g/cm³
الصفراء	0.1767
الرمادى	0.1767

*Fig. 14. The results of density test on two 5 cm * 5 cm PET Samples*

The burst resistance rate for a PET sample reaches about 19.48 mm at 680 N, according to the ASTM D6797 – Standard Test Method for Bursting Strength of Fabrics Constant-Rate-of-Extension (CRE) Ball Burst test. Test Fig. 15.

EN ISO 12236:1996 Geotextiles - Static Puncture CBR

Specimen	Maximum Force N	Displacement mm
1	666	23.08
2	688	17.10
3	685	18.26
Mean	680	19.48

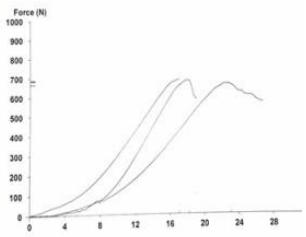

Fig. 15. burst resistance test on a PET Sample.

The results of the Standard Test Method for Thermal Transmittance of Textile Materials test Fig. 16 also showed that the rate of Heat Insulation or Thermal Resistance of PET panels is about 11.15 (Thermal Overall Value) Tog Fig. 17.

*Fig. 16. The thermal resistance test on a 20 cm * 20 cm PET Sample*

Tog Values of Duvets versus Temperature

Air Temp. Centigrade	Summer 3 - 4.5 tog	Spring-Autumn 7.5 - 10.5 tog	Winter 12 - 13.5 tog
24			
23			
22			
21			
20			
19			
18			
17			
16			
15			
14			
13			
12			
11			
10			
9			
8			

Fig. 17. Different Tog values and their indications

For sound insulation, the conducted test on the Two Microphone Impedance Tube device showed the ability of a sample of PET panels with a thickness of about 8 mm to absorb and isolate approximately 20% of sounds, and the percentage increases with the increase in the thickness of the used PET Fig. 18.

Fig. 18. Two-microphone impedance tube device used in sound absorb and isolation test

These panels can also be considered completely safe for public health as they are free of volatile organic compounds (VOCs) such as formaldehyde and other harmful compounds and non-carcinogenic [20].

3.2. SOME EXPERIMENTAL APPLICATIONS ON THE TEST SAMPLES AND ITS USE IN DESIGNING AND FORMATION OF SOME PRODUCTS:

Some test samples were fulfilled to innovate some designs of educational products and children's toys. Manual methods and laser cutting machines were used in the formation of these designs to cut, drill, or hollow out the material. Fig. 19, and Fig. 20 show some samples carried out by the researchers from PET panels to design a puzzle for kids; while Fig. 21 shows the design of an educational game that could help children learn the English alphabet.

Fig. 19. Some samples carried out by the researchers from PET panels as puzzles for kids

Fig. 20. Shows the design of an educational game that could help children learn the English alphabet.

Fig. 21. Shows a colorful puzzle in the form of an Urchin carried out by the researchers from PET panels

4. RESULTS:

By analyzing the previous studies and test results conducted on PET panels' samples to confirm some of their properties, it can be concluded that:

- PET panels are one of the important materials in the field of product design, and reusing them and employing them in the field of product design through recycling helps in the safe disposal of some plastic waste, represented by products manufactured from PET panels.
- Through the conducted laboratory test it was confirmed that a PET panels 5 cm * 5 cm and 8 mm thick, with a weight ranging between 3.22 to 3.53 grams, and a density of about 0.1767 g/cm^3 is able to insulate sound by 20%. As the thickness of the PET panels is directly proportional with the sound isolation percentage, therefore it can be used as soundproof partitions in offices, companies, restaurants, clubs, and open public areas in order to reduce noise and increase privacy rates .
- Using PET panels in product design improves the properties of the products in terms of endurance, durability, thermal insulation, sound insulation, transparency, and aesthetic appearance, in addition to reducing product costs, achieving environmental sustainability, and preserving the environment.
- PET panels can be considered an alternative material for many of the currently used materials due to their multiple properties, cheap price, and eco-friendly.
- PET panels of various types can be considered as one of the most important materials that can be used especially in the field of product design in order to improve the characteristics of the product.

5. DISCUSSION:

Plastic waste is considered one of the main environmental challenges in the modern era, due to its negative impact on both humans and environment. One of the most important types of plastic environmental waste that has accumulated significantly is PET products. The increasing use of PET products has led to global crisis in waste management, as it causes improper disposal of products leading to significant environmental damage. Therefore, it was necessary to recognize a way for safely dispose of PET products and how to apply different forms of PET materials resulting from the recycling of PET products in the field of product design. By conducting some laboratory tests on samples of PET panels to ensure some of the features and characteristics of this material and the ability of applying in the field of product design. It was proven that the explosion resistance rate for a PET sample was about 19.48 mm at 680 N. The thermal insulation test on a PET sample showed that the rate of Heat Insulation or Thermal Resistance of PET panels is about 11.15 (Thermal Overall Value) Tog. Concerning sound insulation it was proven that a 8 mm thick PET panel sample has the ability to isolate approx. 20 % of surrounding sounds and this percentage increases

with the increase in thickness of PET, in addition to its other properties such as transparency, light weight, ease of shaping, scratch and moisture resistance, in addition to its ability to reflect and redirect light, enhance illumination, as by conducting some laboratory tests on PET samples, it has proven good characteristics and possible applicability in using, employing and implementing them in various designs for educational products and children's toys, and aesthetic products. Manual cutting methods and laser machines are used to cut, drill, or hollow out and forming these designs By applying the use of different types of PET panels in various industrial fields, such as wall cladding, partitions, furniture, and decorative elements, and through the previous studies and the conducted test results, it was clear that PET panels are one of the important materials especially in the field of product design. As being a recycled material it can also effectively help in the safe disposal of some plastic waste, mainly PET products. PET panels can also be considered an alternative material for many of the currently used materials due to their multiple characteristics, cheap price, and ease of recycling.

6. CONCLUSION:

The study explores the role of polyethylene terephthalate panels in the field of product design and the way to safely dispose plastic waste in general and PET plastic waste in particular in addition to improving the properties of the industrial design products, as by conducting laboratory tests on some PET samples, it has proven good characteristics and possible applicability in using, employing and implementing them in various designs for educational products and children's toys. Also PET panels can be considered an alternative material for many of the materials currently used in the field of product design due to their various properties, cheap price, and ease of recycling, which improves the properties of the products in addition to its safe disposal which helps in preserving our environment.

7. RECOMMENDATIONS:

- Researchers need to conduct more research and experimental studies on types of PET and how to benefit from them in various fields of industrial product design.
- Product designers should adopt methods for how to reuse and apply different forms of this material into industrial products that have not been used yet, seeking to design and innovate modern products based on the characteristics of this material.

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