Design and Development of High-Performance Composite Fabrics as Sustainable Alternatives to Natural Leather with Enhanced Abrasion Resistance

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Abstract

Increasing demand for sustainable materials has motivated research into alternatives to traditional leather, which reduces environmental and ethical concerns.

This paper discusses the development of an environmentally friendly leather substitute made from cotton, bamboo, and a cotton-polyester blend fabric treated with various silicon and magnesium silicate ($Mg_3Si_4O_{10}(OH)_2$) coatings. The aim is to investigate the mechanical properties of these natural fibers and to determine their potential as wearable replacements for leather composites.

Key characteristics that were treated by the method included thickness, abrasion resistance, and tensile strength. Results indicated that silicon and magnesium silicate-containing coatings considerably improved durability, flexibility, and mechanical properties. These improvements make the thus-treated fabrics potential alternatives to traditional leather.

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The current study will contribute to the growing movement toward ethical and environmentally responsible materials within fashion and textiles by integrating sustainable fibers with value-added treatments, hence offering a solution for reducing the industry's reliance on conventional leather.

Keywords

Leather alternative; sustainability; abrasion resistance; eco-friendly materials.

(1) Introduction

The protein structures of animal hides and skins are altered by physical and chemical processing to produce leather, a robust and adaptable natural product (China, Maguta, Nyandoro, Hilonga, Kanth, & Njau, 2020). Due to its endurance, appeal in clothing, footwear, furniture, and accessories, as well as its inherent physical and visual characteristics, like as warmth, color, and softness (Qua, 2023). It is a widely used commodity, and by 2025, its market share is expected to reach over US$360 billion. Traditionally, leather has been regarded as a byproduct of the livestock business (Gac, Lapasin, Laspiere, et al., 2014). It has nevertheless come under fire for a number of reasons, including being environmentally unsustainable and socially unethical. (Dixit, Yadav, Dwivedi, & Das, n.d.). considering how social standards are evolving and how ecological stewardship is becoming more and more important. After all, among the issues facing the leather business are the substantial greenhouse gas emissions from cow rearing, grazing-related deforestation, and environmental destruction from animal waste. (Gibb, Lees, Pinsky, & Rooney, 2000). Due to toxic chemical involvement and large amounts of sludge waste discharge, while treating raw hides and skins, leather production is not ecologically sound. Tose problems have led to the creation of leather-like materials that are not made from animal products (UNIDO, 2010).

(1-1) Research Problem

1. The negative effects resulting from natural leather manufacturing processes, which contradicts the global trend to reduce pollutants, preserve the environment, and use sustainable materials.

2. The difficulty of using leather is that it is a material that is highly sensitive to environmental factors such as humidity, sunlight, and temperature fluctuations, and it cannot be easily repaired.

3. The environmental burden resulting from industrial textile raw material exhaust.

4. Scarcity of research and experiments in this aspect.

(1-2) Research Objectives

The main objective of this study is to find a more environmentally friendly alternative to leather using natural materials and new manufacturing techniqes.

(1-3) Significance of research

The use of chromium oxides in the tanning process makes natural leather production both environmentally unfriendly and extremely hazardous to human health. However, it is deemed unethical to kill animals for their hides. Nevertheless, using entirely synthetic substitutes is also bad for the environment because they don't biodegradable over time and put a lot of strain on it.

This study aims to use:

1. Natural materials such as cotton and bamboo to decompose environmentally.

2. Use different finishing methods to know their effect on the mechanical properties of natural materials.

(1-4) Research Hypotheses

1. The difference in materials used in the implementation of the samples under study.
2. Different types of finishing materials and techniqes applied to raw materials.

(1-5) Research Field

Fabric industry, Sustainable materials, Fabric mechanical proberties, Leather alternatives, and Fabric testing.

(1-6) Research Methodology

The study was based on an exploratory research design to verify the effectiveness of a natural leather substitute. A descriptive research design was also conducted using a survey method. We made twelve different samples to verify the properties and obtain the best sample that gives us the highest mechanical properties.

(1-7) Previous studies

Pre-tanning and tanning procedures significantly increase the effluent's biological oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS), and other relevant parameters. Consequently, these processes account for 80% to 90% of the pollution generated (Arvanitoyannis & Kassaveti, 2008). produced by the leather sector. These procedures result in the production of toxic gasses like hydrogen sulfide as well as hazardous pollutants including lime and chrome sludge.

Additionally, (Ludvik & Buljan, 2000) states that the post-tanning process of leather manufacture is responsible for (6–11), (24–40), and (8–15) kg/weight of rawhide suspended solids, COD, and BOD, respectively. This means that the tanners must also contend with this issue during the leather-making process. To address these and other environmental and human health concerns related to natural leather and synthetic leather manufactured of polyvinyl chloride and polyurethane, industry professionals and academic researchers have developed alternative bio-leather replacements. These alternatives might provide information about sustainable practices and eco-friendly products.

Bamboo material

The world's fastest-growing wooden plant is bamboo, often known as the "runway name" for enormous wooden plants. Bambos are found in tropical and semi-tropical regions and belong to the Bambusoideae subfamily, which has around 1,500 species. Despite being merely a grass, it is taller than other plants, measuring 30 centimeters in circumference.

Because the cellulose and hemicellulose fibers in the wide and narrow fiber layers are arranged interchangeably and are arranged in different directions and angles within the embryonic matrix along the longitudinal axis of the bamboo fiber, they increase the tensile strength of the fibers, which is why bamboo fibers are also known as natural fiberglass fibers.

The fibers of bamboo can be used to make yarn alone or combined with other fibers like polyester, cotton, viscose, modal, and others. Muso is the fiber used in the textile industry. The bamboo There are numerous uses for bamboo and moso fiber in textile items, including family fabrics, medical gauze, medical masks, undergarments, shirts, pants, towels, and bathrobes. (Meng, 2020).

Characteristics of bamboo fibers

1- Brightness and smoothness with a low rate of wrinkling and shrinkage, and a silky texture that resembles silk without irritating or sensitizing the skin when adhered to

2. The feeling of comfort, which is expressed in the breathability and chilly sensation.

3. The existence of cellulose fibers monolithic in parallel along the longitudinal axis of bamboo fibers results in low weight and strong tensile strength.

4.Biodegradability.

5. The protection it offers from UV radiation

6. The material known as Kun Bamboo, which is closely linked to cellulose molecules in the fiber creation of bamboo fibers throughout the plant's natural growth process, is what gives it its inherent resistance to bacteria and unpleasant odors.

7. A high dyeability. In order to achieve the necessary color level 8, textiles made from bamboo fibers require less dye than those made from cotton.

8. Due to the bamboo fiber's wide breadth and numerous gaps and tiny holes, which absorb and evaporate moisture to provide comfort and ventilation, it has a high absorbability and moisture evaporation rate of up to 13% (Remayanti, 2017).

Limitations of Using Bamboo Fibers:

In addition to its benefits, bamboo cloth has drawbacks, such as:

1. Shrinkage: Bamboo cloth may shrink after washing; therefore, particular cleaning procedures are needed to prevent shrinkage to its usual size.

2. Drying difficulty: Bamboo fabric absorbs moisture and takes a long time to dry and evaporate water, which might impair its structure when wet. This property is similar to that of natural cotton fabric.
3. High cost: Specifically, unprocessed, natural bamboo cloth that contains no additional industrial or semi-industrial fibers (Zhou, 2019).

Cotton Material:

One of the most important industries in the world is the production of cotton, which is done in enormous and cost-effective numbers. Products made of cotton are reasonably priced. Fiber can be produced in a variety of tissue types, from thick velvet to heavy sailing tissue and lightweight laces. Cotton tissue can be used to make a wide range of clothes, home furnishings, and industrial items. It can also be used to make disposable items like tea bags, tablecloths, bandages, costumes, towels, hospital disposable coverings, and other medical applications (Saurabh, 2020).

The following are some of cotton tissue's most crucial characteristics: It is a natural cellulose fiber that is comfortable to wear. Its white color and whiteness index range from 90 to 100. It has a high capacity to absorb liquids, as the cotton cloth can absorb up to 27 times its weight in water. Cotton clothing is comfortable because it absorbs perspiration, which is why towels and bath towels are made of cotton. Cotton tissue has a great color retention rate and can be dyed in a variety of hues. Cotton materials shrink when they are initially cleaned in water, and some cotton garments have already reduced. (Kothari, 2009).

Various processing processes are developed to make cotton resistant to stains, water and mold, crease easily, but many cotton clothes are developed with a finish that helps the fabric to resist crease. The fabric may weaken if cotton is exposed to sunlight for prolonged periods of time, resists static electricity, long staple cotton can be used in soft semi-silky fabrics, characterized by high flexibility ranging from 45% to 74%. Cotton fabric is characterized by its ability to withstand tensile strength. Long exposure to dry heat above 164 ° C will lead to gradual degradation, exposure to temperatures above 262 ° C cause rapid degradation and therefore its heat resistance is relatively high. Its resistance is good for alkalis, its exposure to hot diluted acids has been found to cause its disintegration, as well as for cold concentrated acids, its resistance to organic solvents is good, and it is also resistant to most common industrial and household solvents. Cotton textiles are highly durable and corrosion resistant (Soares, 2008).

Polyester Materials:

Polyester fabric has become one of the most industrial fabrics used in various fields especially in clothing, coverings and other textile industries since the 1930s and 1940s, Polyester tissue is made by mixing coal, water, air and petroleum derived compounds with some acids in a high heat environment This tissue differs in flexibility, durability and ability to maintain its shape according to other chemical compounds that are added to polyester fiber, making it a fabric that can be used in different fields (Demiryürek, 2016).

Polyester is characterized by many things that make it suitable for many uses, the following are mentioned for these qualities

Polyester is a texture capable of probability of light base and acid materials, but it causes its erosion whenever it is in greater concentration and in a higher heat environment, Polyester fibers can tolerate most of the detergent without being adversely affected, but some detergents may cause erosion, such as detergents containing sterile phenol and cloform. High temperature probability, thanks to the high temperature melting polyester which reaches 250-300 ° C, Polyester is characterized by its potential for sunlight and non-corrosive because of it (Gupta, 2008), Polyester greatly absorbs oils, and it is difficult to get rid of oil spots if absorbed, The ease of changing the qualities of polyester and increasing its flexibility and probability of different conditions, according to the method of manufacture, medium to Lightweight making it comfortable to wear for long periods, the durability of polyester fibers; They are better able to resist rupture, amalgamation and spray compared to natural fiber, making them desirable fabrics in the outdoor garment industry, easy to get rid of polyester garment curls, unlike nature fiber as linen and cotton that needs ironing, polyester fiber is water resistant; That is, they do not absorb and do not enter between them, making them stain resistant too, so they are suitable in making rain resistant tents and clothes, but they trap moisture underneath so it is recommended to avoid wearing them during hot seasons, The way polystyrene fiber fabric is made affects its texture, some have a coarse texture, some are soft and resemble the smoothness of natural silk, It is difficult to decompose in nature compared to natural fibers, making it contaminated with them (Belsley, 2006).

(2) Experimental work

This research is concerned with studding the Effect of different finishing materials and techniques on mechanical properties of natural and blended fabrics (abrasion resistance) To enrich it and also improving its properties, meeting the functional purpose it is produced for in this research 12 fabrics were produced according to 2 parameters.

2.1 The Parameters Used for Producing the Samples Under Study:

2.1.1 First Parameter: Reinforcement Material

- Bamboo Fabric.
- Cotton Fabric.
- Blended Fabric (50% Cotton and 50% Polyester).

2.1.2 Second Parameter: Matrix material

- One Layer of Silicon.
- Two layers of Silicon.
- One layer of silicon mixed with Magnesium Silicate ($Mg_3Si_4O_{10}(OH)_2$).
- One Layer of Silicon Mixed with Magnesium Silicate ($Mg_3Si_4O_{10}(OH)_2$), Followed by a Surface Coating of Magnesium Silicate.

Table (1): Parameters used for producing the samples under study.

Samble No.	Reinforcement Material (Fabric)	Matrix Material (Finishing)
1.	Bamboo	One Layer of Silicon.
2.	Blended	
3.	Cotton	
4.	Bamboo	Two Layers of Silicon.
5.	Blended	
6.	Cotton	
7.	Bamboo	One layer of silicon mixed with Magnesium Silicate ($Mg_3Si_4O_{10}(OH)_2$).
8.	Blended	
9.	Cotton	
10.	Bamboo	One Layer of Silicon Mixed with Magnesium Silicate ($Mg_3Si_4O_{10}(OH)_2$), Followed by a Surface Coating of Magnesium Silicate
11.	Blended	
12.	Cotton	

2.2 Specifications (Machine and Fabrics)

Table (2) Specification of the loom used in producing research samples

No.	Property	Specification
1	Weft insertion device	Air jet
2	Name of Loom	MYTHOS
3	Speed of machine	420 picks/min
4	Shedding device	Dobby
5	Width of loom	195
6	Width of fabric	160
7	Reed count (dents/cm)	10
8	Denting	5

2.3 Warp and Weft materials

Warp material for all of produced samples was 100% Cotton with yarn count 80/2 Ne, interlaced with, 100% cotton yarn and 100% Bamboo yarn and 100% Polyester were used for the weft with yarn count 30/1 Ne.

2.4 Laboratory Tests Applied to Samples Under Study

2.4.1 Abrasion Resistance Test

The test was done according to American standard specifications of (ASTM-D-3885-99).

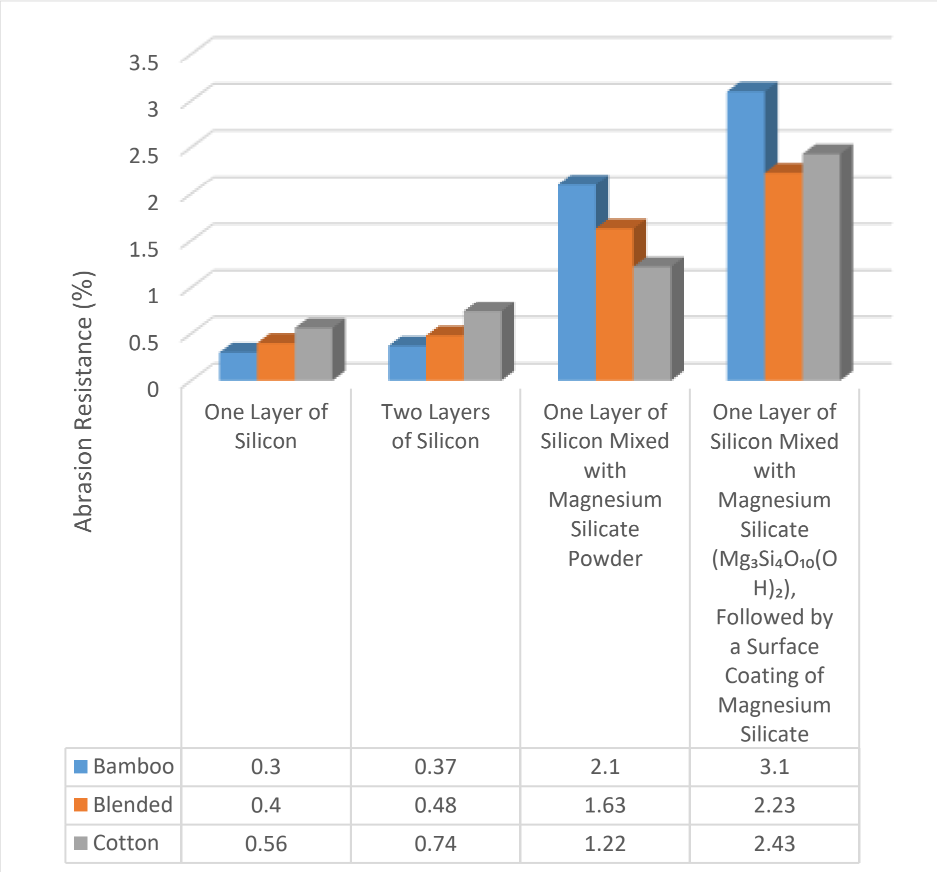
(3) RESULT AND DISCUSSION

The produced fabrics in this research were tested for some essential functional properties which reflected to their end uses.

Table (3): Presents the results of the test to the produced fabrics.

Sample No.	**Fabric Material**	**Finishing Type**	**Abrasion Resistance by Weight**
1.	**Bamboo**	One Layer of silicon	0.3
2.		Two Layers of silicon	0.37
3.		One Layer of Silicon Mixed with Magnesium Silicate ($Mg_3Si_4O_{10}(OH)_2$),	2.1
4.		One Layer of Silicon Mixed with Magnesium Silicate ($Mg_3Si_4O_{10}(OH)_2$), Followed by a Surface Coating of Magnesium Silicate	3.1

5.	**Blended**	One Layer of silicon	0.4
6.		Two Layers of silicon	0.48
7.		One Layer of Silicon Mixed with Magnesium Silicate ($Mg_3Si_4O_{10}(OH)_2$),	1.63
8.		One Layer of Silicon Mixed with Magnesium Silicate ($Mg_3Si_4O_{10}(OH)_2$), Followed by a Surface Coating of Magnesium Silicate	2.23
9.	**Cotton**	One Layer of silicon	0.56
10.		Two Layers of silicon	0.74
11.		One Layer of Silicon Mixed with Magnesium Silicate ($Mg_3Si_4O_{10}(OH)_2$).	1.22
12.		One Layer of Silicon Mixed with Magnesium Silicate ($Mg_3Si_4O_{10}(OH)_2$), Followed by a Surface Coating of Magnesium Silicate	2.43



	One Layer of Silicon	Two Layers of Silicon	One Layer of Silicon Mixed with Magnesium Silicate Powder	One Layer of Silicon Mixed with Magnesium Silicate ($Mg_3Si_4O_{10}(OH)_2$), Followed by a Surface Coating of Magnesium Silicate
Bamboo	0.3	0.37	2.1	3.1
Blended	0.4	0.48	1.63	2.23
Cotton	0.56	0.74	1.22	2.43

Figure (1): The Effect of Material and Finishing Type on Abrasion Resistance

3.1 Abrasion Resistance

The presented work aims at the abrasion resistance of different fabric materials, such as bamboo, blended, and cotton, treated with various types of finishing, namely silicon coatings and combinations of silicon with magnesium silicate. Results presented in the table are based on the percentage of weight loss after abrasion.

3.1.1 Effect of material on Abrasion Resistance:

It can be noticed from figure (1) shows that the bamboo fabric showed the highest abrasion resistance, followed by the blended fabric, and the lowest number was for the cotton material.

Bamboo Fabric: The abrasion resistance of bamboo fabric treated with a single layer of silicon exhibited the lowest weight loss at 0.3%. The abrasion resistance slightly increased to 0.37% with two layers of silicon. However, when a layer of silicon was combined with magnesium silicate, the weight loss significantly increased to 2.1%. This increase in weight loss is further exacerbated when the surface was coated with an additional layer of magnesium silicate, resulting in a weight loss of 3.1%. These findings suggest that while silicon coatings provide a degree of abrasion resistance, the addition of magnesium silicate significantly reduces the fabric's durability against abrasion. Despite this, silicon treatments, especially in one or two layers, seem to make the fabric softer, which could be desirable in applications where softness is prioritized over abrasion resistance.

Blended Fabric: The abrasion resistance of blended fabric followed a similar trend as bamboo fabric. A single layer of silicon resulted in a 0.4% weight loss, while two layers led to a slightly higher weight loss of 0.48%. Incorporating magnesium silicate with silicon raised the weight loss to 1.63%, and the combination of silicon with a magnesium silicate surface coating increased it further to 2.23%. As with bamboo, the addition of magnesium silicate layers appears to compromise the abrasion resistance of the fabric. Nevertheless, the softer feel of the fabric provided by the silicon treatment remains a key benefit, which may be advantageous in consumer textile products.

Cotton Fabric: Cotton fabric showed the highest weight loss after abrasion across all treatments. A single layer of silicon resulted in a 0.56% loss, while two layers increased the loss to 0.74%. Adding magnesium silicate to the silicon coating led to a weight loss of 1.22%, and the final treatment with a surface coating of magnesium silicate resulted in a 2.43% weight loss. Cotton fabric thus demonstrates a lower baseline abrasion resistance compared to bamboo and blended fabrics, with further deterioration in performance when magnesium silicate is added. The silicon treatments did improve the softness of the cotton fabric, which may enhance its appeal in products requiring a gentle, smooth feel, even if the abrasion resistance is compromised.

Table (4) shows the Effect of Finishing on Abrasion Resistance

Fabric Material	Abrasion Test by Weight%
Bamboo	0.3
	0.37
	2.1
	3.1

3.1.2 Effect of Finishing on Abrasion Resistance:

The same figure also shows that the treatment with one Layer of Silicon Mixed with Magnesium Silicate ($Mg_3Si_4O_{10}(OH)_2$) Followed by a Surface Coating of Magnesium Silicate showed the highest abrasion resistance, followed by silicone mixed with Magnesium Silicate ($Mg_3Si_4O_{10}(OH)_2$), followed by a single layer of silicone, and the lowest resistance was for two layers of silicone.

- The **one-layer silicon treatment** generally provided the best abrasion resistance across all three fabric types, with bamboo and blended fabrics showing the lowest weight losses (0.3% and 0.4%, respectively), while cotton fabric showed a slightly higher weight loss (0.56%).
- **Two-layer silicon treatments** further improved abrasion resistance compared to the one-layer treatments, though the improvement was relatively minor (e.g., bamboo increased from 0.3% to 0.37% weight loss).
- The **magnesium silicate treatments**, particularly those involving both a layer of silicon and an additional surface coating of magnesium silicate, led to the highest weight losses in all fabric types. This suggests that while magnesium silicate may offer other benefits in terms of fabric properties, it potentially interferes with abrasion resistance. However, this finishing also made the fabrics softer, which might be an appealing trade-off depending on the desired end-use of the fabric.

Table (5) shows the Effect of Finishing on Abrasion Resistance

Fabric Material	Abrasion Resistance Test%
Bamboo	3.01
Blended	2.43
Cotton	2.23

Conclusion

This study addressed the possibility of using sustainable alternative materials to leather, which poses significant environmental and ethical impacts. The properties of cotton, bamboo, and cotton-polyester blend fabrics treated with silicon and magnesium silicate ($Mg_3Si_4O_{10}(OH)_2$) coatings were considered in this study to assess their potential as substitutes for natural leathers. Consequently, these treatments noticeably enhanced the durability, flexibility, and tensile strength of the fabrics. Results thus show that silicon and magnesium silicate treatments could be added value to creating more sustainable leathers by way of new ecological material development, particularly within fashion and textile fields. Yet, the possibility of further refinement of those materials and exploring their commercial options opens up real opportunities for overcoming several environmental challenges set by traditional leather production.

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تصميم وتطوير أقمشة مركبة عالية الأداء كبدائل مستدامة للجلد الطبيعي مع مقاومة محسنة للاحتكاك

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المستخلص:

لقد أدى الطلب المتزايد على المواد المستدامة إلى تحفيز البحث عن بدائل للجلود التقليدية، الأمر الذي يثير مخاوف بيئية وأخلاقية.

يناقش هذا البحث تطوير بديل جلدي صديق للبيئة مصنوع من القطن والخيزران ونسيج مزيج من القطن و البوليستر والذي تمت معالجته بطبقات مختلفة من السيليكون و سيليكات المغنيسيوم ($Mg_3Si_4O_{10}(OH)_2$). الهدف هو دراسة الخواص الميكانيكية لهذه الألياف الطبيعية و تحديد إمكاناتها كبدائل يمكن ارتداؤها لمركبات الجلود .

و تشمل الخصائص الرئيسية التي تمت معالجتها بهذه الطريقة مقاومة التآكل . أشارت النتائج إلى أن الطلاءات المحتوية على السيليكون و سيليكات و المغنيسيوم أدت إلى تحسين المتانة و المرونة والخواص الميكانيكية بشكل كبير. هذه التحسينات تجعل الأقمشة المعالجة

بهذه الطريقة بدائل محتملة للجلد .

ستساهم الدراسة الحالية في الحركة المتنامية نحو المواد الأخلاقية و المسؤولة بيئيًا في الأزياء و المنسوجات من خلال دمج الألياف المستدامة مع معالجات القيمة المضافة ، و بالتالي تقديم حل لتقليل اعتماد الصناعة على الجلود التقليدية.

الكلمات المفتاحية:

بدائل الجلد؛ الاستدامة؛ مقاومة التآكل؛ المواد الصديقة للبيئة.