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(Review)

The impact of thermal shaping on synthetic fabrics and enhancing the creativity of fashion designers

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ABSTRACT

Fashion is considered one of the tangible and concrete arts due to its fundamental connection to the materials used in its creation. The nature of the material and its potential for shaping, along with the influenced performance techniques, significantly influence the design structure of clothing. Therefore, the broader a designer's knowledge of various materials and their shaping possibilities, as well as the tools that can be employed, the greater their capacity for creative thinking and innovation. The process of thermal shaping of synthetic fabrics involves the application of heat through various means to these materials. This research provides an overview of the factors that have led to the use of synthetic fabrics in thermal shaping, as well as the aesthetic considerations of the thermal shaping techniques applied to the synthetic materials used. It also presents an experiment aimed at identifying the best treatments and shaping methods to control the temperature of synthetic fabrics.

Keywords: thermal shaping, synthetic fabrics, creative thinking, thermoforming, thermoplastic.

1.Introduction

Synthetic fabrics, which have become increasingly prevalent in the field of clothing, are a rich resource for fashion designers, as they can be aesthetically utilized to present distinctive and unique styles. Fabrics, whether natural or synthetic, are considered the raw material that designers use as a medium for expressing their art. "The material is the tangible element for the artist, and for the artwork, it is the jewel of the eye or its body; without it, the artwork is weak and empty".[1-18]

Fabrics made from synthetic fibers are among the best fibers for thermal shaping due to their thermoplastic nature. The structural composition of the material is one of the most crucial factors that influence the various properties of the final design, both physically (mechanically or aesthetically). The ability to shape is particularly significant in clothing design compared to other uses of fabrics, as it plays an active role in determining the final appearance of the design. A designer's knowledge of the properties and capabilities of the material enables them to select the best technical methods for shaping it, achieving a high level of artistic taste, quality, and precision, thereby enhancing its aesthetic and functional value.[10]

Given the nature of synthetic materials, which are strongly affected by temperature variations, the researcher aimed to leverage this property and transform it into advantages that stimulate the designer's creativity, showcasing the results of their innovative thinking.

2. Heat setting process

The thermal setting process is a heat treatment that preserves the shape and wrinkle resistance of fibers. It also contributes to changes in strength, elasticity, softness, dyeability, and sometimes the base color of fabrics. All these changes are associated with the structural and chemical modifications that occur in the fibers. The thermal setting process is also known as the annealing process. The term "degree of thermal setting" is commonly used to describe how close a material is to thermal equilibrium, where a material is at 100% thermal equilibrium at that temperature.

Thermal setting is applied to fabrics made from synthetic fibers such as nylon and polyester, where the fabric is subjected to high temperatures for a short period to create dimensional stability, ensuring that garments made from these fabrics retain their shape during washing and ironing. The primary objective of the thermal setting process is to ensure that the fabric does not change its dimensions during use. A Stenter machine is used for stretching, drying, heat setting, and finishing the fabric (figure 1).

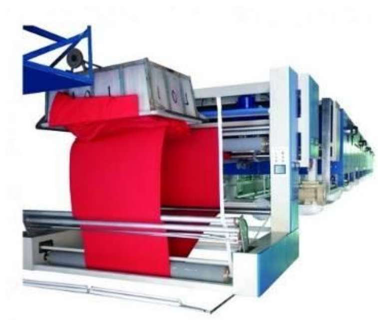


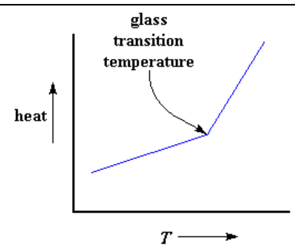
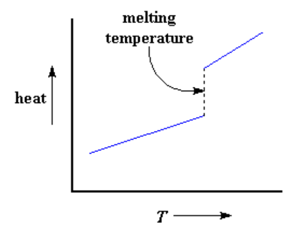
Figure 1. Shows the shape of the tenter machine [19].

Table 1. shows the effect of heat setting on synthetic fabrics and explains the appropriate time and temperature for each material.[1]

Types of fabric	Time (sec)	Min Temp.	Max temp.
Polyester	15-50	170ºC	210ºC
Polyamide 6,6	15-40	170ºC	210ºC
Polyamide 6	15-40	160ºC	180ºC
Triacetate	15-40	160ºC	180ºC
Acrylic	15-40	160ºC	180º-200ºC

The behavior of thermoplastic synthetic fabrics is more complex than that of natural materials. These fabrics undergo processes such as melting, pyrolysis, and evaporation when heated, forming a soft, flowing liquid that can be easily shaped until it cools and solidifies into the desired form.[8] The thermal forming temperature is defined as any point that lies above the glass transition temperature of materials (Tg) and below their melting temperature (Tm). As the temperature of thermoplastics gradually increases, the molecular forces in the polymer chains also weaken progressively until reaching the glass transition temperature. Above the glass transition temperature, the solid material is transformed into a soft and flexible substance resembling rubber, until it is cooled again to return to a solid state after being shaped in its flexible form.

Table 2. Shows a comparison between the glass transition temperature (Tg) and the melting temperature (Tm) [8].

glass transition temperature (Tg)	**melting temperature (Tm)**
It is the temperature at which the polymer changes from the solid glassy state	It is the temperature at which the polymer is converted from the solid state to the liquid state
It occurs in the amorphous phase	It occurs in the crystalline and semi-crystalline phases
It ranges between a temperature below Tg and room temperature	It ranges between room temperature and a temperature higher than Tm
The state of the polymer is flexible, soft and malleable	The polymer state is strong and solid
	

Examples of some phase transformations of synthetic fabrics:

- **Polyester:**

Is a synthetic polymer with (ester-co-) groups. Polyester melts rather than burns. Polyester is a type of plastic (polyethylene terephthalate). Polyester melts when exposed to indirect heat but will not withstand direct flame.

- Melting Point: 482°F (250°C).
- Autoignition Temperature: 842°F (450°C).
- Variables: The length of time exposed to high heat sources will affect the plasticization of the fabric. The thickness of the fabric and whether it is mixed or arranged with other materials will ultimately affect the melting rate and plasticization temperature.[5]

- **Nylon**:

- Nylon is a class of thermoplastic polymers used in the manufacture of synthetic textiles (-CONH-). There is a numbering system for grades in relation to the chemical composition of nylon (the most common are 6, 66, 11, and 12). Nylon melts and does not burn.
- Melting Point: 428-554 °F (220 °C to 290 °C).

- Variables: The temperature ranges depend on the chemical composition of nylon, i.e. the grade of nylon number. For example, nylon 6 melts at the lower end of the spectrum, 220 °C or 428 °F. [5]

2.1. The role of material in stimulating the innovative process for fashion designers:

The innovative thinking abilities of a designer are what allow them to deviate from traditional paths, breaking rigid molds and transcending conventional norms to achieve designs characterized by novelty, not only in their elements but also in their organization and the synthesis between them through innovative formal relationships. Developing these abilities is one of the most important factors that enhance the quality of design. Innovative capabilities may manifest in the designer's awareness of the tools, materials, artistic methods, and previous experiences available to them, in addition to their ability to explore a diverse array of arts from their environment and its contents. The goal is to reshape these elements to achieve a cohesive and aesthetically innovative unity, solidified in distinctive compositions.[2]

Many fashion designers have been influenced by the technique of free-form fabric thermoforming, which has been utilized in their innovative designs. **Below is a presentation of some designers who have employed similar techniques in their designs, which have significantly impacted the level of innovation in their work:**

2.1.1. Mariko Kusumoto:

Kusumoto draws her inspiration from natural sources. Most of her works are made from resins and synthetic textile fibers, and her creations tend to exhibit significant technical complexity. Since her works are inspired by natural forms, the accessories she designs, which evoke the transparency, delicacy, and lightness reminiscent of plants and animals in the marine world, appear enchanting (figure2).

Figure 2. Sample of Katsumoto's work [20].

Her works have been featured in many museums and exhibitions, including the Renwick Exhibition at the Smithsonian American Art Museum, where the Seascape 1 necklace in polyester fabric, (Figure 3), the Musée des Arts Décoratifs in Paris, the Ring Redux Exhibition at the SCAD Museum of Art in Georgia, USA, which shows the “Purple Dewdrop” ring in polyester organza and sterling silver, (Figure 4), and the Musée des Arts Décoratifs in Paris, where the “Gathering-White” brooch is on display and is now in the permanent collection, (Figure 5).

Figure 3. Seascape 1 necklace illustrates [20].

Figure 4. Purple Dewdrop Ring [20].

Figure 5. Gathering-White Brooch [20].

2.1.2.Benjamin Shine:

American artist Shine has devised a method for creating three-dimensional paintings from remnants of tulle fabric. At first glance, when viewing his artwork, one might think it is painted with watercolors; however, upon closer inspection, it becomes apparent that it consists merely of layered, stacked pieces of colored mesh tulle, along with some additional elements. Shine is renowned for capturing facial details through shading and silhouette by directly ironing tulle fabric, as illustrated in (Figure 6) featuring portraits of window displays at Bergdorf Goodman from July 7 to August 3, 2017, in New York City.

Figure 6. shows Bergdorf Goodman outlets [17].

Shane has collaborated with many fashion houses. Utilizing his skills in tailoring and pattern making, along with his techniques that make tulle fabric move to create dynamic art. We see this in Shane's collaboration with fashion designer John Galliano for the Spring 2017 collection of Maison Margiela Artisanal, where we observe the "face coat," reminiscent of a model engulfed in a smoky apparition (Figure 7).

Figure 7. John Galliano’s Spring 2017 collection for Maison Margiela [17].

2.1.3.Michelle Griffiths:

She is a teacher and the global Shibori representative in the United Kingdom/Ireland. Her works are permanently displayed in her gallery/studio at the Model House Craft & Design Centre. She lives and works in South Wales, where she continues to develop a Shibori study center through a series of Shibori workshops. Her work explores the natural rhythm of traditional Shibori techniques to create contemporary three-dimensional sculptures. Michelle primarily works in white and off-white, documenting the practical steps of the Shibori technique, including stitching, binding, assembling, and folding. During these processes, the fabric undergoes color changes through dyeing, altering its texture and shape.

Figure 8. one of her works titled Bubble Wraps [9].

Figure 9. one of her works titled AntiGravity5 [9].

3.Results and Discussion

This part provides an overview of the factors that led to the use of synthetic fabrics in thermoforming and discusses the aesthetic data related to the thermal forming technique of the utilized synthetic materials. It presents an experiment to determine the best treatments and shaping methods for regulating the temperature of synthetic fabrics.

Most synthetic fabrics are made of thermoplastics, which are easily heat-formed. The study relied on fabrics containing high percentages of polyester or polyamide (nylon). For this, samples of commercially available lightweight and medium-weight polyester and nylon fabrics such as polyester organza, satin, and tulle were used. So, the fabric chosen by tested by direct heat and the fabrics that did not decompose and formed were tested by the tests that will be shown. After conducting thermal analysis tests on the fabrics under study, appropriate fabric samples were used with each design considering the results.

3.1 Differential Thermogravimetric analysis (DTGA):

- The analyses were conducted at the Microanalysis Laboratory, Faculty of Science, Cairo University, Thermal Analysis Laboratory.
- The analysis follows the quality standards specification (ASTM E1131).

The test is used to characterize materials in terms of their composition. The device allows the measurement of thermal events that do not produce a change in mass such as melting, glass transition, and other changes, giving us information about the physical properties of the material such as evaporation, sublimation, melting, crystallization, and in chemistry, absorption and change of state.[15]

Table 3. shows sample No: 1

NO.	Fabric name	Scientific basis	Thickness	Weight
1	satin	100% Polyester	0.486 inch	279 g/m

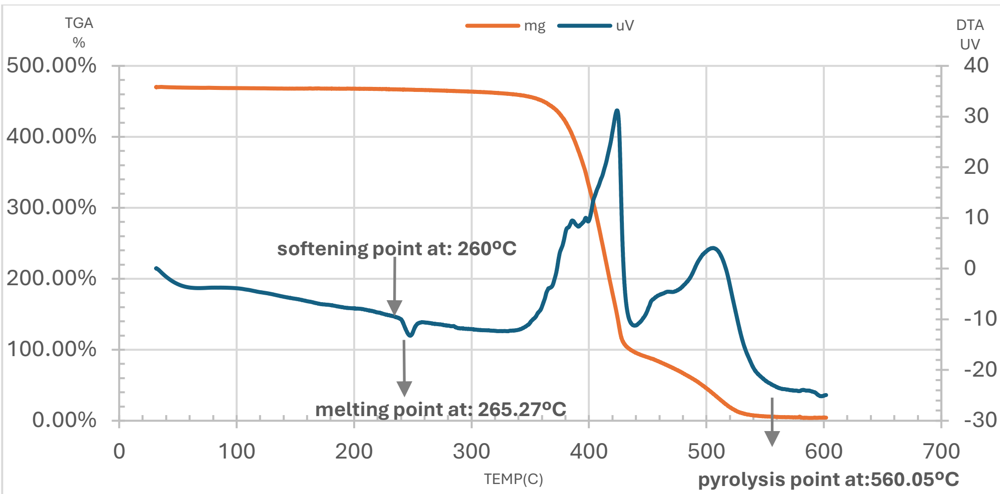


Figure 10. Graph showing the thermal analysis of sample 1

Table 4. Shows the thermal decomposition values of sample 1

Sample NO.	Glass transition point Tg-ºC	Melting point Tm-ºC	Thermal decomposition point Tp-ºC
1	260 ºC	265.27ºC	560.05 ºC

Softening point which the material becomes malleable for the sample 1 being tested is: 260 ºC

Melting point which the material changes to its initial phase state of what resembles a liquid for the sample 1 being tested is: 250 ºC.

Pyrolysis point which the material decomposes into its initial components, causing a change in the chemical state accompanied by a physical change, for the sample 1 being tested is: 560.05 ºC.

Table 5. shows sample No: 2

NO.	Fabric name	Scientific basis	Thickness	Weight
2	Tulle(crystal)	100% Polyester	0.175 inch	14 g/m

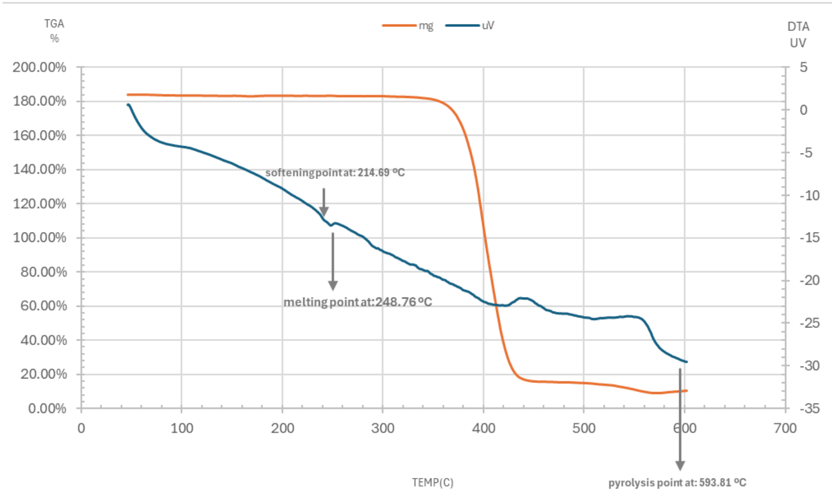


Figure 11. Graph showing the thermal analysis of sample 2

Table 6. Shows the thermal decomposition values of sample 1

Sample NO.	Glass transition point Tg-ºC	Melting point Tm-ºC	Thermal decomposition point Tp-ºC
2	214.69ºC	248.76ºC	593.81 ºC

Softening point which the material becomes malleable for the sample being tested is: 214.69 ºC

Melting point which the material changes to its initial phase state of what resembles a liquid for the sample being tested is: 248.76 ºC.

Pyrolysis point which the material decomposes into its initial components, causing a change in the chemical state accompanied by a physical change, for the sample being tested is: 593.81 ºC.

Table7. shows sample No: 3

NO.	Fabric name	Scientific basis	Thickness	Weight
3	Polyester organza	100% Polyester	0.122 inch	49 g/m

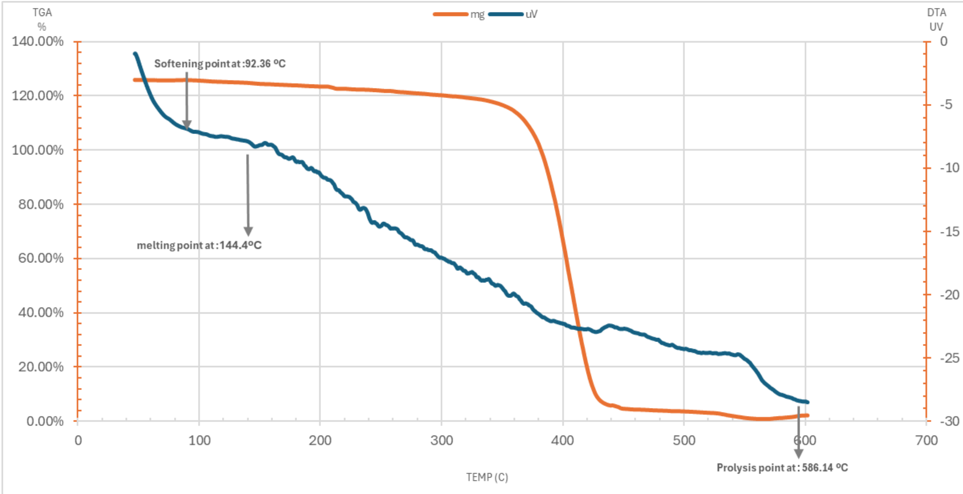


Figure 12. Graph showing the thermal analysis of sample 3

Table 8. Shows the thermal decomposition values of sample 3

Sample NO.	Glass transition point Tg-ºC	Melting point Tm-ºC	Thermal decomposition point Tp-ºC
3	92.36ºC	144.4ºC	586.14 ºC

Softening point which the material becomes malleable for the sample being tested is: 92.36 ºC

Melting point which the material changes to its initial phase state of what resembles a liquid for the sample being tested is: 144.4 ºC.

Pyrolysis point which the material decomposes into its initial components, causing a change in the chemical state accompanied by a physical change, for the sample being tested is: 586.14 ºC.

Table 9. shows sample No: 4

NO.	Fabric name	Scientific basis	Thickness	Weight
4	Polyester organza	100% Polyester	0.108 inch	16 g/m

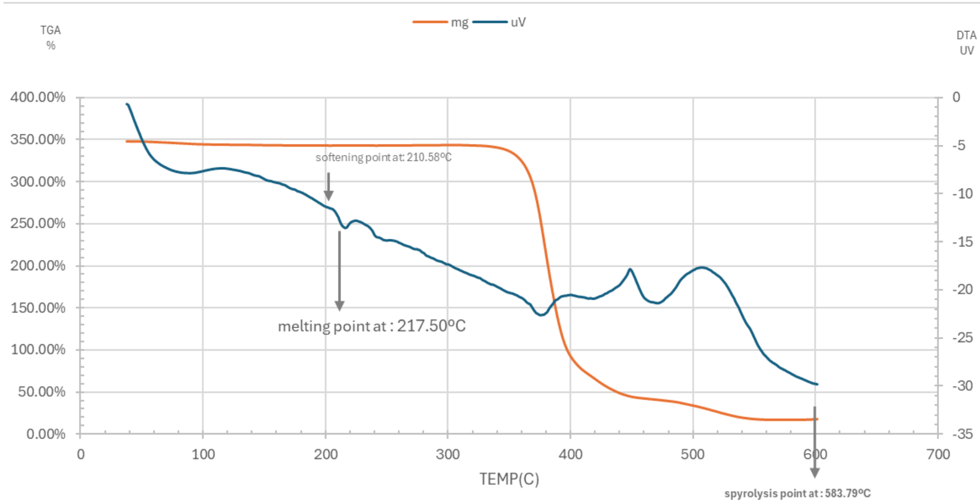


Figure 13. Graph showing the thermal analysis of sample 4

Table 10. Shows the thermal decomposition values of sample 4

Sample NO.	Glass transition point Tg-ºC	Melting point Tm-ºC	Thermal decomposition point Tp-ºC
4	210 ºC	217.50ºC	583.79 ºC

Softening point which the material becomes malleable for the sample being tested is: 210 ºC

Melting point which the material changes to its initial phase state of what resembles a liquid for the sample being tested is: 217.50 ºC

Pyrolysis point which the material decomposes into its initial components, causing a change in the chemical state accompanied by a physical change, for the sample being tested is: 583.79 ºC

Table 11. shows sample No: 5

NO.	Fabric name	Scientific basis	Thickness	Weight
5	Polyester organza	100% Polyester	0.072 inch	14 g/m

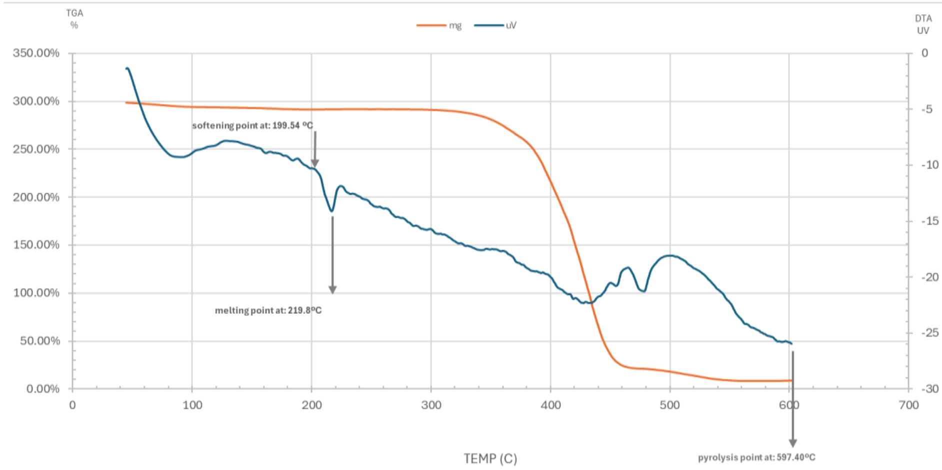


Figure 14. Graph showing the thermal analysis of sample 5

Table 12. Shows the thermal decomposition values of sample 5

Sample NO.	Glass transition point Tg-ºC	Melting point Tm-ºC	Thermal decomposition point Tp-ºC
5	199.54 ºC	219.8ºC	597.40 ºC

Softening point which the material becomes malleable for the sample being tested is: 199.54 ºC

Melting point which the material changes to its initial phase state of what resembles a liquid for the sample being tested is: 219.8 ºC

Pyrolysis point which the material decomposes into its initial components, causing a change in the chemical state accompanied by a physical change, for the sample being tested is: 597.40 ºC

Table 13. shows sample No: 6

NO.	Fabric name	Scientific basis	Thickness	Weight
6	Polyester organza	100% Polyester	0.074 inch	17 g/m

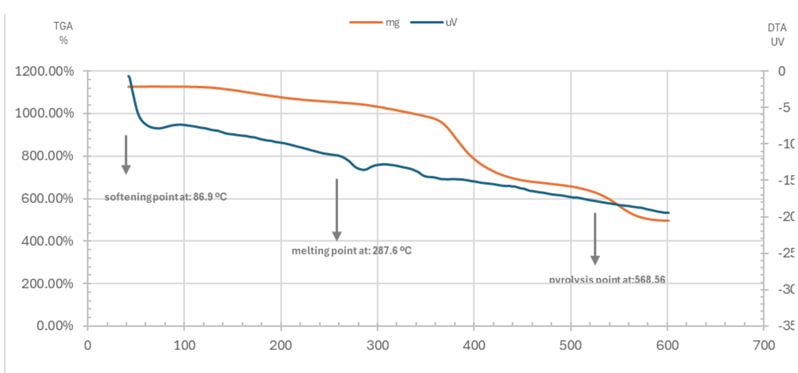


Figure 15. Graph showing the thermal analysis of sample 6

Table 14. Shows the thermal decomposition values of sample 6

Sample NO.	Glass transition point Tg-ºC	Melting point Tm-ºC	Thermal decomposition point Tp-ºC
6	86.9 ºC	287.6ºC	568.56 ºC

Softening point which the material becomes malleable for the sample being tested is: 86.9 ºC

Melting point which the material changes to its initial phase state of what resembles a liquid for the sample being tested is: 287.6 ºC.

Pyrolysis point which the material decomposes into its initial components, causing a change in the chemical state accompanied by a physical change, for the sample being tested is: 568.56 ºC.

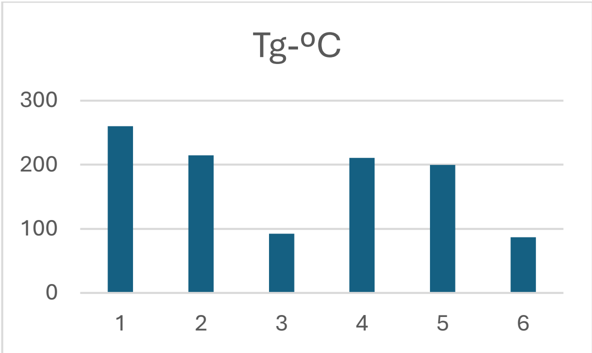


Figure 16. Graph showing is the evaluation of the degree of vitrification for the fabric samples analyzed

From the (figure 16) we prove the reason that When using Welding machine in burning fabric formation, when making close holes, the fabric of the package with the fabric sample (6) (figure 17A) is damaged, while it was not prepared and did not remain damaged in the unit implemented with the fabric sample (4) (figure 17B).

A

B

Figure 17. thermoforming a unit of organza fabric using Welding machine, (A) The effect of burning on fabric with a high degree of vitrification and the lack of impact on fabric when making closely spaced holes. (B) The effect of burning on low vitrification degree fabric, where the unit was damaged due to increased hole density.

3.2 Statistical differences of the weights of the analyzed samples:

- The test follows the quality standards specification (ASTM D3776 / D3776M - 09a).

Table 15. Shows the weights of the fabric samples that were tested.

sample NO.	w1(g/100cm²)	w2(g/100cm²)	w3(g/100cm²)	average(g/100cm²)	average(g/m)
1	2.7884	2.7883	2.7884	2.788	279
2	0.1695	0.1695	0.1695	0.17	17
3	0.29	0.2902	0.901	0.494	49
4	0.1634	0.1636	0.1638	0.164	16
5	0.1404	0.1404	0.1404	0.14	14
6	0.1711	0.1712	0.171	0.171	17

From the previous table that the heaviest fabric is satin, which explains its suitability for free use when shaping it dry with a heat gun. In contrast, when executing thermoforming with a heat gun on tulle fabric, it deteriorates upon exposure to the heat gun (figure18).

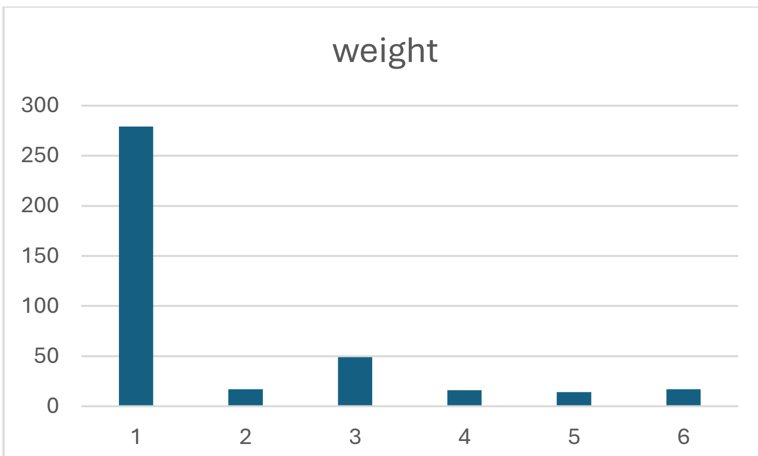


Figure 18. Graph showing Shows the order of samples by weight

It has been observed that high-weight organza fabrics exhibit a pronounced shaping effect when compared to low-weight organza fabrics. This is illustrated in the following figure, where the shaping effect is clearly evident in (figure19A), while it appears less pronounced in (figure19 B), as noted in the second chapter of the practical section.

A B

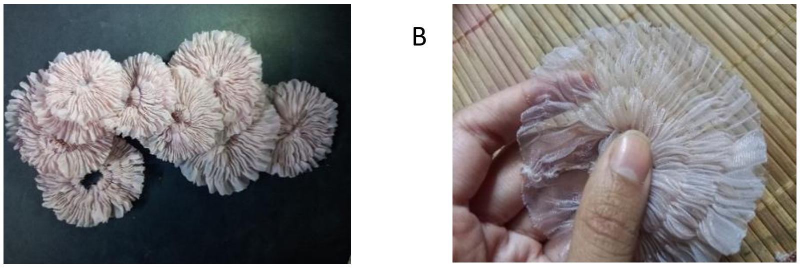


Figure 19. thermoforming a unit of organza fabric using wet thermoforming, (A) thermoforming unit on heavy weight organza fabric. (B) thermoforming unit on lightweight organza fabric.

4. Applied designs:

Three designs were implemented, with the researcher ensuring the execution of all design elements to foster motivational environments and assessing the role of the employed thermoforming techniques in stimulating innovation during direct implementation.

4.1 Applied design 1:

A B

Figure 20. applied design 1, (A) overall view of applied design 1. (B) final sketch of applied design 1

A

B

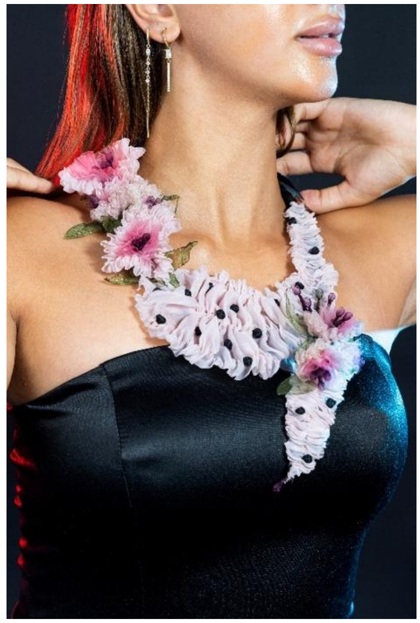


Figure 21. applied design 1, (A) details view of applied design 1. (B) necklace in details

- **Thermoforming method:**

Using lightweight and heavier pink polyester organza fabric involved cutting longitudinal strips from both types and burning the edges after cutting to prevent fraying. A large stitch gauge (size 5) was then used to sew four lines along the length of the cut strip, followed by pulling the thread tightly to create the desired shape (figure 22)

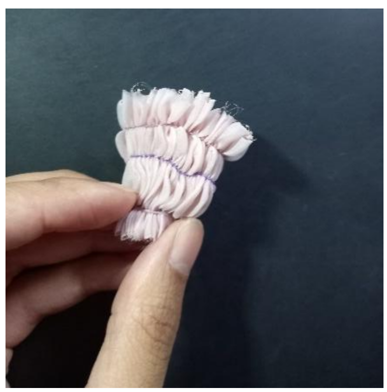


Figure 22. shows the shape of the rose after it is sewn and the thread is joined to create pleats

After preparing them, the units are placed in a pot of boiling water for 30 minutes for high-weight fabric and 20 minutes for lower-weight organza. After ensuring that the unit is dry, both ends of the tape are sewn with a transparent nylon thread, then the thread that was sewn initially is removed to join the breaks.

The petals are also made by wet shaping, using organza fabric and a metal pin with an oval head. The pin is covered with organza fabric and the thread is wrapped under the head and along the metal part. Then the formed units are placed in a pot of boiling water for up to 20 minutes. After ensuring that they are dry, the thread is removed (figure 23).

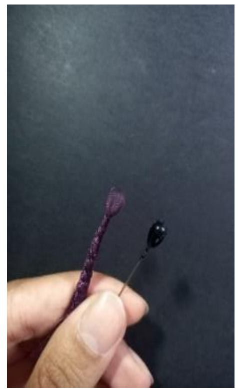


Figure 23. Shows the shape of the metal pin used to make the petal

As for the leaves, they are formed dry, where the entire area of the fabric is exposed to the heat gun (Figure 24 A) and then the shape of the paper units is cut, and the edges are burned as shown in the (figure 24)

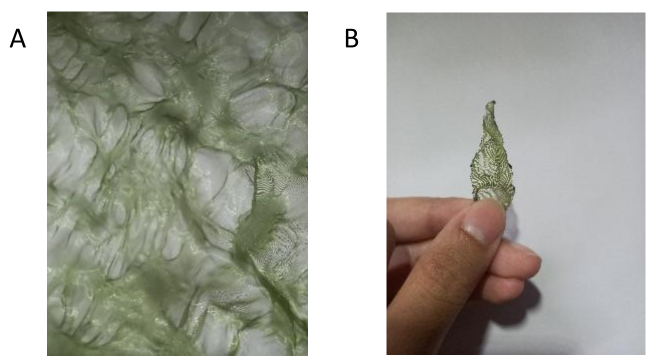


Figure 24. (A) The shape of the fabric made from the leaves after using heat gun. (B) Shows the shape of the leaf after cutting it from the shaped fabric and gluing the edges using the burning technique.

4.2 Applied design 2:

A

B

Figure 25. applied design 2, (A) overall view of applied design 2. (B) final sketch of applied design 2

A

B

Figure 26. applied design 2, (A) overall view of applied design 2. (B) details view of applied design 2

- **Thermoforming method:**

This dress relied on the dry thermoforming technique, as the bottom layer of satin fabric was shaped directly with a heat gun to give the appearance of bubbles of graduated density (figure 27).

Figure 27. shows the effect of a heat gun (dry thermoforming) on a satin fabric layer

The tulle fabric was directly formed on the upper layer of the dress (organza) using a steam iron, by controlling the shadow gradations of the tulle fabric, which has a high degree of transparency. To add depth to the fish shape(figure 28 A), a piece of fabric was added in a wet formation, by wrapping a group of beads in a piece of organza fabric, then placing it in a pot of boiling water for up to 20 minutes, and when it dries, it is fixed to the body of the fish (figure 28 B), and so on until the entire design is formed.

A B

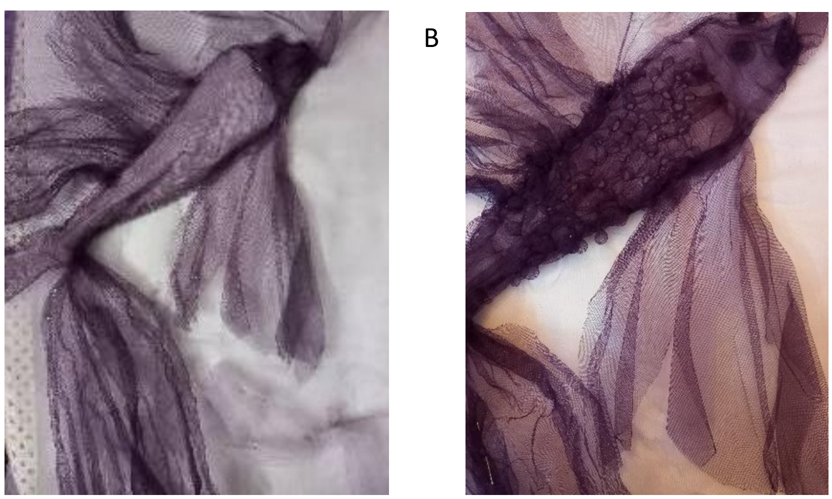


Figure 28. (A) Shows one of stages of shaping a fish shape with tulle fabric. (B) Shows the shape of the fish after adding the raised part formed in a wet thermoforming technique.

5. Conclusion

Through conducting the previously presented laboratory experiments and implementing the final designs, the researcher has concluded the following:

1. It is possible to develop treatments and formative methods to extract new decorative formats with innovative characters using synthetic fabrics.
2. The fabric is a fundamental element in design; it guides the designer and transitions them from the realm of thought and imagination to the world of reality and application. A designer may be inspired by a specific material, which may suggest ideas suitable for design. As the execution begins, the material continues to provide numerous ideas that converge to form a final innovative concept that embodies the material's characteristics of texture, color, lighting, and flexibility, utilizing all these properties to arrive at the optimal aesthetic form of the design.
3. The analytical study of existing research has provided diversity in designs, as the combination of synthetic materials has added a variety of textures to the surface of the design. This has allowed to produce designs with aesthetic values that may aid in extracting a set of principles utilized to enrich the field of fashion design.
4. The practical framework reflects many observable phenomena that stimulate the mind and senses. I "reorganize" them into a new presentation that can be described as unexpected or innovative. I always prefer to leave some room for the viewer's imagination. This experimentation stimulates the process, leading to incidental discoveries that, in turn, generate new innovative ideas.

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