**Egyptian Journal of Chemistry**

**http://ejchem.journals.ekb.eg/**

# Application of Carbon Dioxide Laser Irradiation in Engraving Polyester and Cotton-Based Textiles

**Reem M. Nofal* [a], Sarah M. Sharaf [a], Enas M. Sakr [a]**

[a] *Faculty of Women for Arts, Science and Education, Ain Shams University, 1 Ahmed Tayseer St., Heliopolis, 11566, Cairo, Egypt*

**Abstract**

Laser technology is one of the most important modern technologies in the field of industry, which achieve the concept of sustainability. It is considered one of cleanest industrial methods especially in the field of clothing and textile industry.

This study uses the carbon dioxide laser ($CO_2$) as the most common using in clothing applications which applied by using engraving technique on the fabrics were produced using 3 different types of fibres (100% cotton, 74%cotton/25%polyester/1% lycra and 100% polyester). The $CO_2$ laser parameters used was power (20, 40 & 60 w), speed (300,400 & 500 mm/s) and step (0.1, 0.2, 0.3 & 0.5 mm).

In this paper, the effects of engraving parameters on three different fabrics used in the search were investigated to determine the optimum parameters to apply it. Therefore, the impacts of these parameters selected on crease recovery, tensile strength, tearing strength properties, colour change and surface morphology on these fabrics were investigated.

The low laser power and high-speed parameters was the best results applied on engraving the research fabrics. The rate of yellowing and change in colour increases as the speed decreases. On the other hand, the variable steps of laser were as applied to reach the best application of laboratory tests to engraving fabric surface.

*Keywords:* $Co_2$ laser ; engraving parameters; textiles; sustainability.

## 1. Introduction

Laser technology is one of the most important modern technologies in the industry, especially in clothing and textile. A laser beam is continuous, intense, with highly focused energy, and can create unique, innovative, and accurate designs. Laser technology is the most widely used technology in the field of textiles because of the many techniques it offers that support the concept of sustainability [1]. Therefore, it is considered one of the cleanest industrial methods in the field of textiles [2].

Applications of laser technology in the textile industry include fabric fault detection, laser cutting, welded garment production, laser marking, barcode scanning, laser fading, and laser engraving, in addition to modifying the surface properties of the fibre to improve its properties such as wetting behavior, friction, adsorption ability, and adhesion of dyestuff pigment in the dyeing process [1,3,4].

Depending on the physical nature of the active medium, the lasers are divided into Gas Lasers, ex: Helium-Neon Laser, Argon and Krypton Ion Lasers, and Carbon Lasers (CO2 laser). Solid-state lasers include Ruby Laser, Nd: YAG, and Titanium Sapphire (Ti: sapphire). Semiconducting lasers, also known as laser diodes [5].

Using carbon dioxide gas laser in the clothing industry globally in 1960, as it is considered the most widely used type of laser gas and the best in most industries in general [6]. It uses infrared light with a wavelength of 10.6 micrometers, allowing it to absorb through nonmetallic materials such as wood, plastic, paper, leather, and textiles [7]. A $CO_2$ laser can be worked in a continuous wave or pulse [8,9]. The carbon dioxide laser is more suitable and efficient for engraving materials because they are not good conductors of electricity and heat [10]. So, it is the most common in clothing applications due to its low price and non-toxicity [7,11,12]. As well as, it has found solutions to reduce the environmental problems caused by the traditional processes of fabric, including physical processes for example sanding, sand spraying, embroidering brushing, and chemical processes, for example, stone washing with enzymes, snow washing, rinsing, pre-washing bleaching, by saving energy and reducing water and harmful chemicals caused by these processes, as well as creating designs that are easy to modify and apply to the material with

*Corresponding author e-mail: reem.nofal@women.asu.edu.eg .; (Reem M. Nofal).
Receive Date: 28 March 2023, Revise Date: 13 April 2023, Accept Date: 11 May 2023
DOI: 10.21608/EJCHEM.2023.200446.7792

less damage in addition to the ability to achieve sustainable design [2,8,13].

There are many advantages of the engraving process on fabric materials, including the stability and management of the laser source led to high quality, treatment of most textile materials, speed, high accuracy, and clarity of design details on the material, environmentally friendly operations; it does not need to use chemicals to complete the process, increased productivity, and accuracy [14]. Vector, raster, and projection are ways of laser engraving operations [15]. The effect of $CO_2$ laser beam, can also produce various engraving effects on the fabric̀ s surface by changing the operating conditions, and among these fabrics are jeans, where the engraving process can remove a layer from the surface of the fabric at different depths or remove the surface dye based on the final use, the executed design, and the control of the laser variables used(Kan et al., 2010) [16]. With the help of computer-aided design, designs can be created on jeans fabrics for the ability to control the variables to get a change in colour without damage to the fabric, as it is considered the easiest and fastest way to etch on jeans for accuracy and ease of operation compared to traditional processes [3,14]. Controlling the variables of the engraving process is very important to reduce damage to the fabric and avoid adverse physical changes to the fabric [17,18]. Therefore, Laser technology achieves sustainability by achieving high quality through its different technology. It is also called a clean and dry process because it is free from wastewater and chemicals harmful to the environment [15].

In this study, the laser $Co_2$ will be used to engraving (100%cotton,74%cotton/25%polyester/1%lycra,100 %polyester) fabrics to investigate the optimum condition of laser variables (power/speed& step) which suitable to applied with these fabrics. As well as study the fabrics crease recovery, tensile strength, tearing strength properties, colour change and surface morphology on these.

## 2. Materials and methods

### 2.1. Fabrics

Specification of fabrics used in the study are described in table (1) were obtained from Al-Robaiah Textile Factory, Gesr Al-Suez, Cairo.

### 2.2. Laser machine specification

The laser machine used in experimental work was $CO_2$ Laser machine which is described in the (table 2) that is used for cutting and engraving on different materials, including cloth, wood and leather, paper, and others. The laser operations were carried out at the CNC Al-Obour Center, Cairo Governorate.

**Table 1:** Fabric specifications used in engraving techniques.

| Sample No | 1 | 2 | 3 |
|---|---|---|---|
| Weight | 398 g/m$^2$ | 343 g/m$^2$ | 371 g/m$^2$ |
| Fabric composition | 100% cotton | 74%cotton 25% polyester 1%lycra | 100%Polyester |
| Weave structure | Twill 3/1 Z | Twill 3/1 Z | Plain 1/1 |
| No. warp thread in cm | 26 | 39 | 32 |
| No. weft thread in cm | 17 | 26 | 27 |
| Colour | Ocean blue/75 (Indigo dye) | (Indigo dye) | Dark brown |

**Table 2:** $CO_2$ laser specification machine.

| | |
|---|---|
| Model | SA1610 |
| Laser Type | CO2 Class IV |
| Laser Power | 100 W |
| Processing Area | 100X100 mm |
| Power Supply | AC 220 V±10% 50Hz\60Hz |
| Total Power | 1250 w |

### 2.3. Laser process

#### 2.3.1. design Preparation

The design used in the research was created by the Adobe Illustrator software for the ability of the program to create vector-based designs for the possibility of communicating the design with the laser software machine's program (RuiDa ACs work) to adjust the technology variables according to the techniques and used material.

#### 2.3.2. Laser engraving technique parameters

Laser engraving parameters include step (distance between two consecutive passes of a laser beam), power (output power of laser) [3] and speed (the passage of laser head) [19]. The engraving process was carried out using the raster method at constant height of the laser machine's head (0. 6mm). Table 3. shows the used laser parameters.

**Table 3:** laser engraving parameters.

| Parameter* | Value | | | |
|---|---|---|---|---|
| Power (w) | 20 | 40 | 60 | - |
| Speed (mm\s) | 300 | 400 | 500 | - |
| Step (mm) | 0.1 | 0.2 | 0.3 | 0.5 |

*W= watt, mm=millimeter, s= second

The process was carried out by constant speed (300mm/s) and the lowest step (0.1mm) and gradually changing the power(20-40-60W) from low to high and then gradually increasing the speed(400-500mm/s) with changing the power to reach the best variable from power and speed on the material used. Applying the variable steps (0.2-0.3-0.5mm) at the optimum parameters of speed and power to reach the best variable through the application of laboratory tests to engraving fabric surfaces.

**2.3.3. Laboratory methods of inspecting fabrics**

**2.3.3.1. Crease recovery test**

The test is to be administered according to the Standard Test Method (M&S P22) [17]. The test was conducted in the physical testing lab of Golden Tex Factory, 10th of Ramadan.

**2.3.3.2. Tensile Strength and elongation test**

The tensile and elongation strength was measured according to (ASTM D76-93) [18]. The test was carried out at the chemical laboratories of the armed forces, Nasr City, Cairo Governorate.

**2.3.3.3. Tearing strength test**

The tearing strength was measured by (ASTM D2261-96) [19]. The test was carried out at the chemical laboratories of the armed forces, Nasr City, Cairo Governorate.

**2.3.3.4. Scanning Electron Microscopy Analysis**

Morphological analysis was examined using a Scanning Electron Microscope type FEI Czec. which consists of high vacuum sample chamber of 60 P, accelerating voltage 20.0 kV, Backscatter electron detector (BSED), Working distance of 10 mm, Spot size 5 and Magnification for the analysis was 2,000X.

**2.3.3.5. Investigation colour change by gray scale**

AATCC gray scale for colour change procedure is used to determine the colour change and rate of yellowing induced for fabrics after laser engraving to investigate the quality and optimum parameters for fabrics engraving technique [23]. According to the Grayscale test, the untreated sample, and the treated sample with the variables of the laser study are placed, side to side, in comparison with the Standard Gray Scale panel with a rating from (1-5) under its illumination D65.

## 3. Results and discussion

### 3.1. Effect of laser parameters on fabrics engraving properties

laser beam parameters as (power, speed, and step) described in table (3) were applied to the research samples 100% Cotton, Cotton /Polyester/Lycra, and 100%Polyester fabrics that were previously described. Visual examinations and, mechanical tests were done.

#### 3.1.1 The effect of laser speed and power parameters on 100% cotton fabric

Research parameters started at a constant speed (300 mm/s) and step (0.1mm) and gradually change the power (20,40,60 W) respectively. As shown in (Fig.1 a-b-c) represent the effect of speed parameter at different power values.

Yellowing and weakness in fabrics are detected at power (20 W), (Fig. 1a). Complete burn and dissolve of cotton fibres at power (40&60W), (Fig. 1b, c). At constant speed (400mm/s) as shown in (Fig. 1 d-e-f) for laser power (20W) the material surface is slightly change to yellow and weakness occurs with partial dissolve at power (40W) and complete dissolve of cotton fibres at power (60W). This is due to prolonged exposure period to laser beam power. For speed (500 mm/s) at power (20W) the surface of fabric is clear from any thermal effects as shown (Fig. 1g) compared to same power at low speed (Fig. 1 a-d). Due to short period that fabric exposed to laser power and its thermal effect. Also (Fig.1 1h-i).100%cotton fabric is affected greatly at speed (500 mm/s) and power (40W) as fabric was burn the engraved surface with erosion of cotton fabric surface and partially dissolve cotton fibre surface at power (60W) occurred.

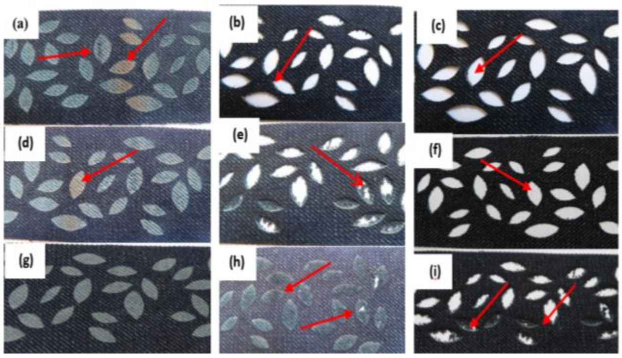



**Figure 1:** Effect of laser power parameters at constant step 0.1mm for 100%Cotton fabric. Samples (a-b-c) represent power 20,40&60 W respectively at constant speed (300mm/s). Samples(d-e-f) at constant speed (400mm/s). Samples (g-h-i) at constant speed(500mm/s).

As previously shown in (Fig. 1), it can be concluded that by increasing the laser beam power, the more damage of cotton fabric is occurred. Cotton fabric start to be affected by thermal effect of laser irradiation from yellowing phenomenon to degradation and complete dissolve due to the absorption of the thermal energy resulting from the power of the laser beam on the cellulose fibres, which causes drying of the cellulose fibres and thus cracks and decomposes of the cellulose fibres upon swelling and bursting due to the absorption of high thermal energy through the power of the laser beam as reported in [24]. Therefore, the low power (20W) and high speed (500 mm/s) is giving the optimum conditions for engraving results for 100% cotton fabric, so variables of step parameters (0.2-0.3-0.5mm) are applied to be tested to ensure the quality of fabric after laser treatment.

#### 3.1.2. The effect of laser speed and power parameters on cotton/polyester/lycra blended fabric

As revealed in (Fig. 2), the effect of speed parameters at blended polyester, Lycra, cotton fabric is shown at speed (300-400mm/s) for power (20W) (Fig. 2 a, d) the fabrics are subjected to yellowing and weakness. Complete dissolve and burn at fabric laser treated parts at power (40 and 60W) as shown in (Fig. 2 b, c, e and f) due to long period of exposure for power laser ray which causes high thermal energy. At speed

(500mm/s) sample (Fig. 2g) are clear from any defects and give optimum engraving result. For sample (Fig. 2b) the fabric is subjected to yellowing and burn at treated areas but for sample (Fig. 2i) fibres are damaged completely with remaining residues burning fibre at treated surfaces. The sample at speed (500 mm/s) at same power have less effect compared with low speed due to the short period that fabric was exposed to laser power ray.

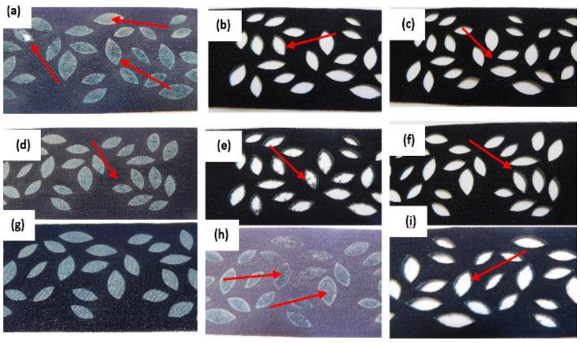


**Figure 2**: Effect of laser power parameters at constant step (0.1mm) for Cotton, Cotton/polyester/ Lycra blended fabric. Samples (a-b-c) represent power (20, 40 &60 W) respectively at constant speed (300mm/s). Samples (d-e-f) at constant speed (400mm/s). Samples (g-h-i) at constant speed (500mm/s).

Low power (20W) has fewer adverse effects on samples compared with high power (40 and 60W) as shown in (Fig. 2). The fabric material started to be affected by the laser thermal energy effect at power (20W) and that increase in power with consider speed parameter. Power (40&60W) have intensive, damaged effects on material due to the energy emitted by laser rays was very strong and therefore this power not suitable for blended fabrics. Lower power (20W) and high speed (500mm/s) are suitable for sample fabric and are considered as the optimum laser for Cotton, Cotton/polyester/ Lycra fabric engraving effects.

### 3.1.3.The effect of laser speed and power parameters on 100%polyester fabric

Laser Speed (300mm/s) and power (20W) that shown in (Fig. 3a )has a deep engraving effect compared to sample at speed (400 and 500 mm/s) as shown in (Fig. 3 d, g) due to long period that fabric exposed to laser power rays. Also, adverse effects of speed occurred in power (40 and 60W) by remove and dissolve large ratio of synthetic fibres that form fragile layer of dissolve fibres as shown in (Fig. 3 e-h). Remain residual dissolve fibres at engraved parts according to the amount of laser power that absorbed by fibre that depend on the period that fabric expose to laser rays. (Fig. 3 c, f, and i) are excluded as the effect of laser reaches to cutting effect.

As shown in (Fig. 3) it can be concluded that the effect of high laser power on synthetic fabrics are caused high percentage of dissolved fibres related to the high energy emitted from power laser rays. When compared with subjecting fabric surface to different speed ratios, it can be observing the damage of fabric. Low power (20W) at speed (400 and 500mm/s) are the suitable for polyester fabric. As it gives engraved surface free from damage as deep engrave reaching to cutting fabric or weak dissolve fibre layer. Therefore, the best optimum laser speed condition at (500 mm/s) was chosen to save time and best engraving quality for 100%polyester fabric surface.

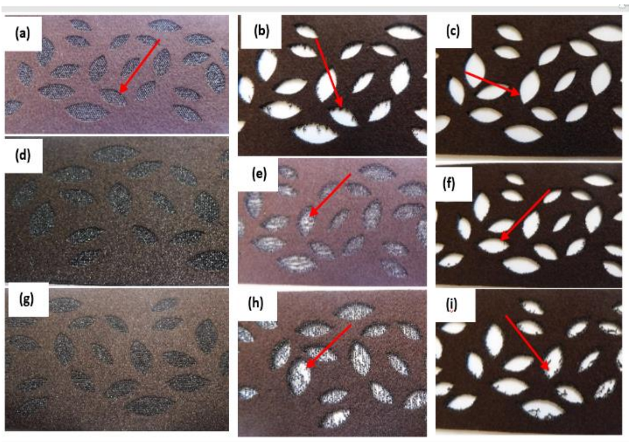


**Figure 3:** Effect of laser power parameters at constant step (0.1mm) for 100% polyester fabric. (a-b-c) represent power (20,40& 60 W) respectively at constant speed (300mm/s). (d-e-f) at constant speed (400mm/s). (g-h-i) at constant speed (500mm/s).

### 3.2. Effect of laser engraving parameters on colour change by gray scale for different research fabrics

The Grayscale test was applied to evaluate fabrics appearance and quality treated with laser rays. Treatments with a low laser power as (20W) at different speeds (300,400 and 500mm/s) is suitable with less adverse effects as discolouring, although the higher power (40 and 60W) caused the burning and melting of the research fabrics. Grayscale is used to determine the optimum parameter by measuring the thermal effect from colour shade change and yellowing rate in range from (1-5) which (5) representing no colour change.

Table (4) shows that the speed parameter of (500mm/s) achieves the best results on the research samples. The Cotton, Cotton/polyester/ Lycra blended fabrics were obtained (3-4) for the clarity of the engraved places without signs of burns or yellowing resulting from the thermal laser effect. The polyester fabric also represented an acceptable degree (4-5) compared with the lower speeds. This indicates that a speed parameter of (500mm/s) at a power of (20W) is suitable for the research fabrics. The lower the speed,

the greater the fabrics yellowing for the 100%cotton and Cotton, Cotton/polyester/ Lycra blended fabric, while the colour change increase for the polyester fabric.
Colour change evaluated by comparison of untreated sample and the samples after laser step variable at power (20W) &speed (500mm/s) through gray scale grade (5), which represented no colour change and so good engraving effect. Table (4) shows that the speed parameter has a significant effect on the colour change, at step parameter (0.1mm), speed 500 mm/s which is an optimal parameter on all research fabrics (cotton and cotton/polyester/Lycra blend fabric and polyester fabric).

**Table 4:** Colour change for (cotton, cotton/polyester/Lycra and polyester fabric) at step (0.1) and speed parameters at constant power 20W.

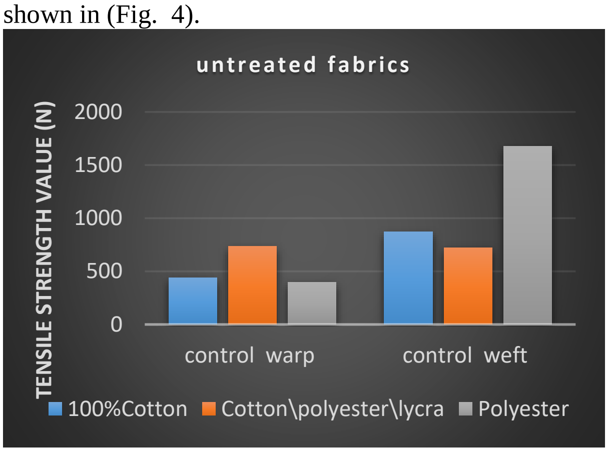
| Fabrics | Cotton | Cotton/polyester/ Lycra | Polyester |
|---|---|---|---|
| *Colour change at speed parameter* | | | |
| 300mm/s | 1 | 1 | 4-3 |
| 400mm/s | 3 | 2 | 4 |
| 500mm/s | 3-4 | 3-4 | 4-5 |

*1 means high change, while 5 means no change

Because of the laser effect focused on the treated surface area, and therefore a larger percentage of colour fading effect occurred as the dye was removed on the surface of the fabric, thus increasing the clarity and impact of engraving on the surface of the fabric. On the contrary, the polyester fabric acquires a degree of darkening when exposed to heat due to the dissolving and re-hardening of the fibres, which makes the treated areas darker [25].

### 3.4. Effect of laser engraving parameters at tensile strength and elongation on research fabrics

Tensile strength is measured for laser treated samples at speed (500mm\s), power (20W) and different step parameters. The tensile strength values are decreased in general at step parameters than untreated fabrics as shown in (Fig. 4).



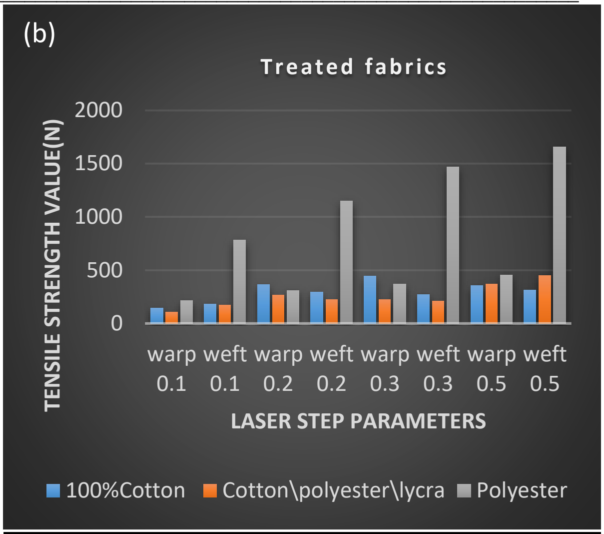




**Figure 4:** Tensile strength value (a) Untreated fabrics (100%cotton, cotton \polyester\Lycra blend and polyester fabrics) (b)Treated laser at speed (500mm\s), power(20W) and different step parameters.

As shown in (Fig. 4), in laser step value (0.1mm) there is high degree of decrease of tensile strength values for both warp and weft direction than other step values (0.2-0.3-0.5mm), due to number of engraved lines in (0.1mm) step parameter is high than other step value so, it induced great decrease in tensile strength values. 100% Cotton fabric was significantly affected when exposed to the lowest step variable due to the passage of the laser rays closer and thus a higher degree of the laser beam existence on the surface of the fabric, which means the effect of its composition and the weakness of the material. The decreases due to the formation of pores on the surface of the fibres. Many pores mean greater weak points on the fibres, which means a lower tensile strength value [26].
In Cotton/polyester/ Lycra blended fabric also the tensile strength decreases in both directions which warp yarns represent cotton while weft yarns are polyester and Lycra. The presence of thermoplastic fibres as polyester and Lycra fibres that caused the cotton fibres to be merged because of their melting and hardening. Due to the melting of polyester fibres and the presence of pores and cracks on the cotton fibres [27]. Also, the weave structure (twill 3/1) is a factor in decreasing the tensile strength in the direction of the warp, so that most of the cotton fibres are in the direction of the warp, making it more effective with laser rays due to its float on the surface of the fabric, so that the polyester & Lycra fibres have fewer intersections, which makes the warp threads slide easily because it contains fewer weak points that it consists of polyester and Lycra fibres, in which the dissolution of the fibres is much higher. Decrease in the value of the tensile strength in the two directions of warp and weft, which indicates damage to the fabric structure and the percentage of different the decrease in tensile strength depends on the material used. [13]

As a result of preserving the durability of the fabric for tensile strength when compared to the untreated samples as clear in the (Table.5) and achieving an optimal engraving quality at closer radius distances, the step variable (0.2 mm) is optimal on 100%cotton which caused the less tensile strength reduction that reaches up to (16.85%) in warp and (66.09%) in the weft direction and Cotton/polyester/ Lycra blended fabrics which up to (64%) in warp and (69.25%) in weft direction.

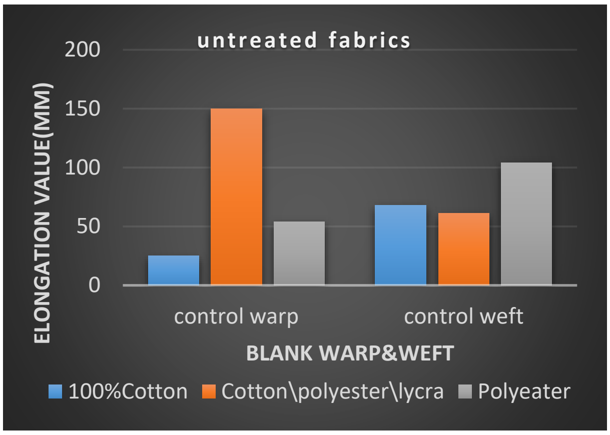
From the previous (Fig. 4 a-b), when comparing the untreated fabric with the laser step parameters of the polyester fabric, the reason for the decrease in the tensile strength value of the warp and weft directions is the lower the step parameter, given that the focus of the laser beam is greater, and thus, when some polyester fibres are dissolved, the fibres merge because of their melting and rehardens, and weakens the fabric because of the restriction of the movement of the threads. From the previous, step parameter (0.3mm) is the most durable for tensile strength and a good engraving result, so it is considered the optimal variable for polyester fabric which caused the tensile strength reduction that reaches up to (6.56%) in warp and (12.39%) in the weft direction.

As shown in (Fig.5 a-b) &(Table.6), the elongation values of the untreated samples compared with treated fabrics, at the optimal step variable for each fabric, 100%cotton fabric was not affected much and elongation is reduced to (26%) in the direction of the weft threads due to the formation of pores and cracks on the surface of the fibres [26]. On the other hand, the friction force between the warp threads is less due to the distance between the threads in the weaving structure (Twill3/1) of the fabric and thus the ease of pulling them.

The ratio of the elongation is decrease to (40%) in warp and to (27%) in weft direction due to the cracks and re-Harding polyester and Lycra fibres [26]. The decrease in warp direction is due to more affect by laser beam because the weave structure (twill 3/1) where most of the warp threads are located on the face of the fabric. For 100%polyester fabric indicate to optimum step (0.3) the elongation not greatly effect where compared with untreated fabric as shown in (Fig. 5 a-b), the increased in warp direction about (11.53%) due to increasing its density.

**Table (5).** Effect of laser step parameter on the tensile strength(N) of research fabrics.

| *Treating condition* | *Cotton* | | *Cotton/polyester /Lycra* | | *Polyester* | |
|---|---|---|---|---|---|---|
| | *warp* | *Weft* | *warp* | *weft* | *warp* | *weft* |
| *control* | 439 | 870 | 735 | 722 | 396 | 1678 |
| *0.1mm* | 144 | 183 | 106 | 175 | 213 | 782 |
| *0.2mm* | 365 | 295 | 264 | 222 | 311 | 1147 |
| *o.3mm* | 444 | 274 | 225 | 210 | 370 | 1470 |
| *0.5mm* | 355 | 316 | 369 | 450 | 457 | 1656 |



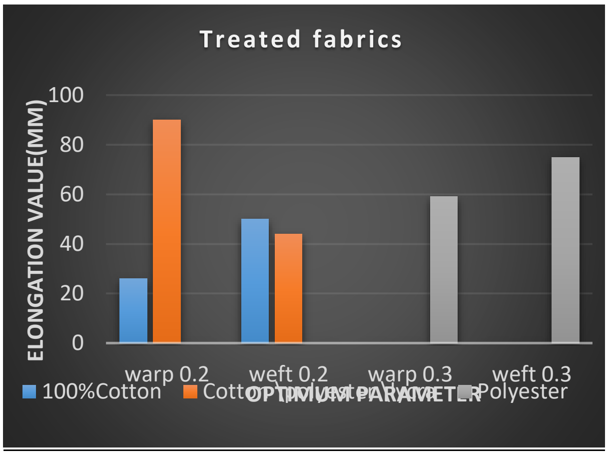




**Figure 5:** Elongation ratio (a)untreated fabric (Cotton, Cotton/polyester/ Lycra, and Polyester) (b) laser treated fabrics at optimum conditions. speed (500mm/s), power(20W) and step (0.2mm) for cotton & Cotton, Cotton/polyester/ Lycra, and Polyester, and (0.3mm) for polyester fabric.

The fusion of the synthetic fibres could also be looser and re-hardening again, giving stiffness to the fabric with the presence of the weave structure factor, which is plain 1/1, meaning that all the threads are compact, so that the movement of the threads is more difficult to move. The elongation decreased about (8.9%) in general because of removing part of the material and thus the weakness of the material, which means that there was damage to the fabric so, percentage of damage is lower at parameter (0.3mm).

**Table (6).** Effect of laser optimum parameters on the elongation ratio (MM) of research fabrics.

| **Treating condition** | **Blank (untreated)** | | **Laser treated fabrics at optimum conditions** | |
|---|---|---|---|---|
| | *Warp* | *Weft* | *Warp* | *Weft* |
| **100%Cotton** | 25 | 68 | 26 | 50 |
| **Cotton/polyester/ Lycra** | 150 | 61 | 90 | 44 |
| **100%Polyester** | 54 | 104 | 59 | 75 |

### 3.5. Effect of laser engraving parameters on the Tearing strength property for different research fabrics

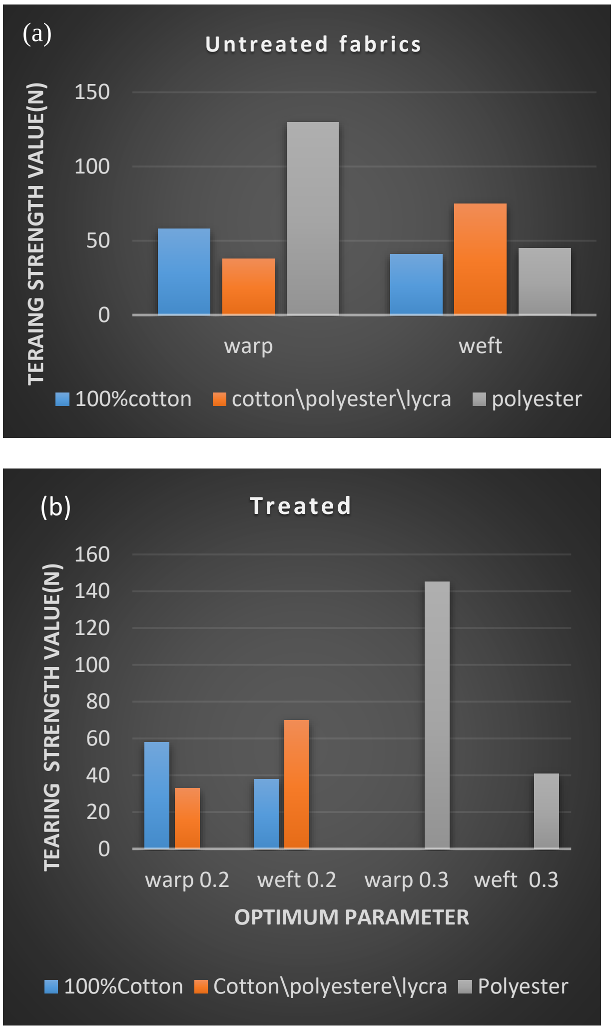



Figure 6: Tearing strength value (a) untreated fabrics (100%cotton-cotton \polyester\Lycra-polyester), (b) Optimum treated fabrics at speed (500mm\s), power(20W) and step (0.2mm).

As shown in (Fig. 6) the tearing strength value of treated and untreated 100% cotton fabric are measured, the fabric maintains its resistance to the tearing force in both directions, so that it decreases to about (7.31%) from its original value in weft direction as a result of the fibre damage, due to the thermal effect resulting from the laser beam treatment, as indicated in studies [13,17] Where the fibres are affected by formation of pores on cotton fibre that weak fabric to resist tearing strength.

Also, the value of the tear strength decreased in warp about (13.15%), and weft about (6.6%) for the Cotton/polyester/ Lycra blended fabrics, due to the exposure of the fibres to the thermal effect resulting from the laser beam. The fusion of polyester fibres and Lycra fibres make the fabric more rigid due to their merging and covering the cotton fibres, and reduced the movement of the fibres, and this led to the hardness.

The value of the tear strength of the polyester fabric differs in the direction of the warp than the weft, where its value increased in the direction of the warp about (11.53%) due to the density of the warp threads and thus the increase in the stiffness of the fabric after melting. On the other hand, weave structure (plain 1/1) has effect on the resistance of the broad fabric to tearing strength, as the intersections between the threads are many and give it special strength when exposed to laser beams, as the polyester fibres, which are characterized by their strength, melt and re-harden again, and thus the fusion of the fibres more, which means an increase in the strength of the fabric. Decreased value of the tear in the direction of the weft about (15.15%), so, this confirms that the fabric has acquired hardness and cohesion of the fibres after the laser engraving process.

### 3.6. Effect of laser engraving parameters on the crease recovery on different research fabrics

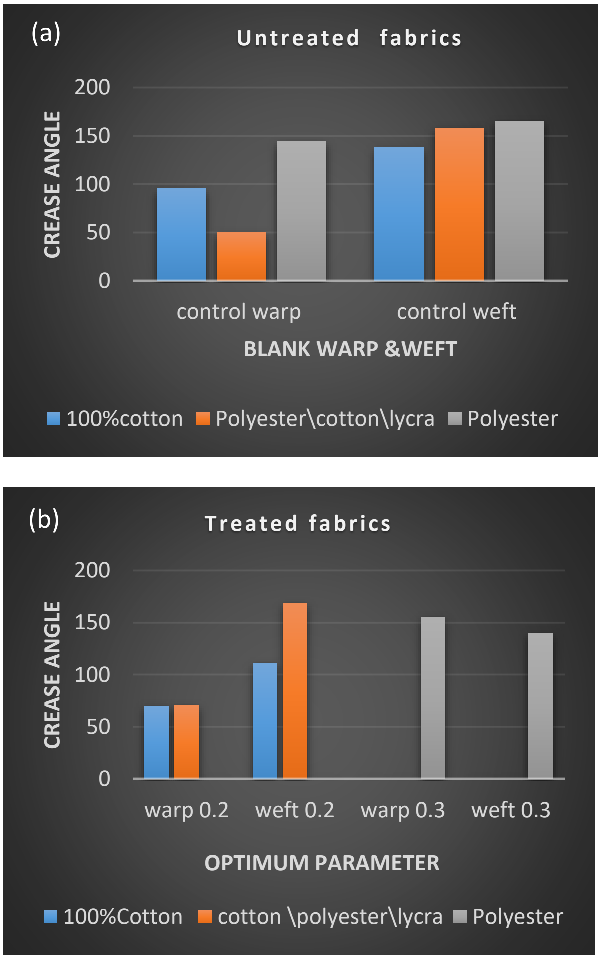



**Figure 7:** Crease recovery (a)untreated (Cotton -Cotton/Polyester/Lycra and Polyester) (b) Optimum treated fabrics at speed (500mm/s), power(20W) and step (0.2mm) for 100%cotton &Cotton/Polyester/Lycra and (0.3mm) for polyester fabric.

As shown in (Fig. 7), the value of crease resistance angle decreased for 100% cotton in both directions in the warp to (26.5%) and weft to (19.57%) when compared with untreated which means fabric become softer and more prone to crease as indicated by [17].
For Cotton/polyester/ Lycra blended fabric crease angle increase at both warp direction to (41.2%) and weft direction to (6.64%) directions after applying laser engraving process fusion of polyester fibres and Lycra fibres, which leads to the encapsulation of the cotton fibres, making them more resistant to crease. Lycra fibres are also another reason in fabric gaining crease resistance because of its elastic properties. Thus, when fused with polyester fibres, cotton fibres gain greater resistance to crease, and thus improve the properties of the fabric. as the study [28]. Polyester fibres have a high resistance to crease and wrinkling due to the very high crystallinity ratio. The polyester broadcloth fabric was characterized by its thickness and weight. The crease angle increased in the direction of the warp to (7.6%) compared to the control sample, due to the density of the warp threads is greater than the weft, which makes it give greater rigidity to the material, especially after applying laser irradiation beams on it due to its melting and re-hardening again. The decrease in weft direction up to (15.15%) due to remove and dissolve more of fibre on surface fabric, so its weakness and inability to resist crease.

**3.8. Effect of $CO_2$ laser parameters on fabric Surface morphology by (Scanning Electron Microscope) analysis**

***100%cotton***

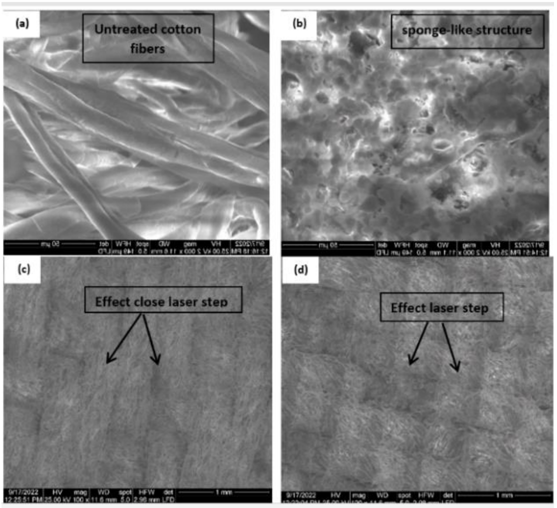



Figure 8: Microscopic images (SEM) of sample (1) 100% cotton. (a)control sample. (b) cotton fibre laser treatment in power 40 W and speed 500 mm\s at step 0.1mm with, magnification 50 µm. (c-d) effect of laser at constant power 20 and speed 500 which (c) step 0.1mm and (d) step 0.5 mm with magnification 1mm.

(Fig. 8 a) shows the shape of the untreated cotton fibres with smooth fibres surface. (Fig. 8b) shows SEM sponge-like structure that formation of pores at (40 W) and speed (500 mm\s) for cotton fibres absorbed thermal energy emitted by the laser beam, due to the swelling of the cotton fibres and their explosion, due to the evaporation of carbon dioxide gas and the vaporization of water because of the high energy thermal. Studies confirmed this are [4,24]. The higher the ratio of the pores, the greater the damage to the fabric [29]. The number of pores will increase with the increase of laser processing parameters. which is verified by [4]. The higher the ratio of the pores, the greater the damage to the fabric [26]. The number of pores will increase with the increase of laser processing parameters. which is verified by [4]. The higher the percentage of pores, the greater the effect of laser radiation on the surface of the fibres, and the greater the depth of engraving. This study [4] indicated that the percentage of the area of the pores on the surface of the cotton fibres reaches 31% at the highest energy density, and therefore the engraving was not superficial on the cotton fabrics, which led to a partial loss of the surface of the fibres, which means a high-impact engraving. From (Figure8b) the change of the shape of the cotton fibres to a structure similar to sponge-like structure as a result of the presence of a very large percentage of pores, which means that the effect was not superficial and resulted in a high engraving depth may be approximately reach to 75%.
Thermal damage resulting from increased laser energy leads to dehydration of cotton fibres (oxidation) to produce decomposed fibres and carbonization to occur [30]. Fibre degradation when laser power density increase [17, 31]. The cotton fibres begin to turn yellow as a result hydrocellulose's produced when aldehyde and carboxylic acid groups are formed because of chemical degradation, which occurs when the glucosidic linkages are broken by the combined effects of heat, moisture, and oxygen in the air. As the temperature rises and oxidation of the cotton occurs, the cotton turns a yellow-brown colour that gradually darkens to a darker brown [32] . (Fig. 8 c-d) showing the difference between effect of laser step parameters, as step (0.1mm) have large effect on cotton fibre due to closer rays of laser beam to each other that have dense effects than step 0.5mm. The amount of fibre removed in parameter (0.1mm) more than (0.5mm), so when the step was increasing the area of the laser effect is decrease [28].

***Cotton\Polyester\Lycra***

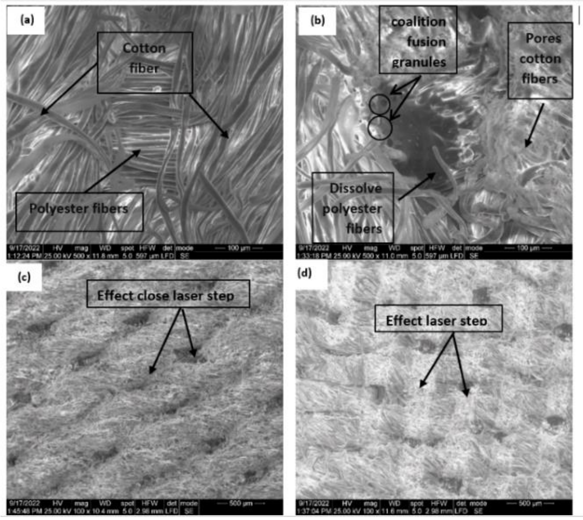



Figure 9: Microscopic images (SEM) of sample 75%cotton 25%polyester 1%lycra. (a)control sample. (b) fibres treated with power 40 W and speed 500 mm\s with, magnification 100 µm. (c-d) effect laser at constant power 20 and speed 500 which (c) step 0.1mm and (d) step 0.5 mm with magnification 500 µm

According to (Fig. 9 a) cotton, polyester, and Lycra fibres without laser treatment, which cotton fibre in warp yarn. Polyester fibres have a smooth surface compared to cotton fibres, which have wrinkles and grooves. In (Fig. 9 b), the effect of laser beam power on cotton and polyester fibre which the polyester dissolves. In contrast, cotton fibre has a sponge-like structure to merge and fuse the fibres, making them weak fabric points. The fusion of polyester fibres and cotton fibres at specific parts of the fibres forms small grains because of the melting of the polyester fibres and re-hardening them again [4]. The high energy did not only affect the surface of the fibres, but also partially eroded the cotton fibres and caused the dissolution of a large part of the polyester fibres. The higher the energy, the greater the damage to the fibres. A study [4] indicated that increasing the laser energy increases the melting rate of polyester fibres to reach 56%, which means melting a large percentage of the threads to give a smooth surface and a greater depth of engraving. From the (Figure.9b) the effect of the engraving was not superficial on the fabric, but rather it was a complete melting of the surface to disappear the vision of the less affected fibres in the treated area to show a large percentage of the melted polyester weft fibres and the formation of a large percentage of gaps on the cotton fibres and the loss of a large part of the surface of the fibres to confirm the depth of the engraving greater that reach to approximately 75% of the surface of the fabric.

The difference between the (Fig. 9 c-d) had the effect of the fibre step variable. The impact of the step (0.1mm) was more significant because of the increasing the effect of the laser beam on the material. It can be observed that there is a large area affected by the laser beam that appeared in the formation of pores on the surface of the fibres and the dissolution of the polyester fibres due to the passage of the beam closer, which means an increase in its effect on the fibres. At (0.5mm). The surface effect of the fibres exposed to the laser beam and the simple solubility of the polyester fibres compared to the amount present in (0.1mm) variable. The higher the step variable, the reduce the effect of the laser beam on the fibres [28].

***Polyester***

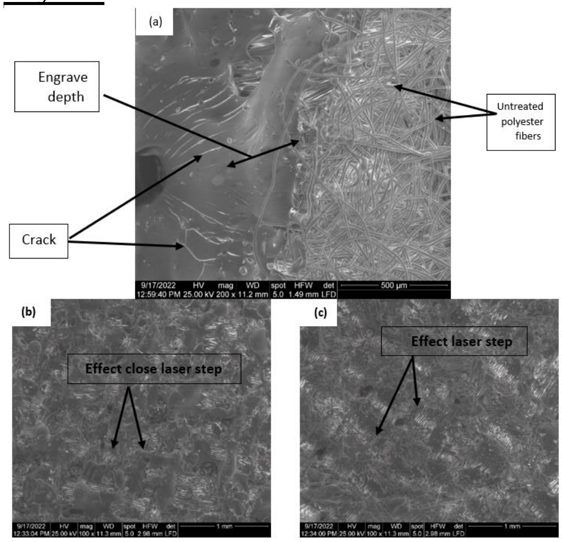



Figure 10: Microscopic images (SEM) of sample 100% polyester (a) not laser effected polyester fibre and fibres affect in power 40 W and speed 500 mm\s with, magnification 200 µm. (b-c) effect laser at constant power 20 and speed 500 which (c) step 0.1mm and (d) step 0.5 mm with magnification 1mm.

As shown in (Fig.10 a), it can be obvious polyester fibre after and before exposure to laser rays. Polyester fibre appears clear and smooth in two kinds of shapes lint fibre and filament fibre in warp and weft yarn. due to intensity of laser power formed thin a cracked block of polyester. The porosity of fabric surface change due to melt polyester fibres therefore laser power has strong effect [33]. The presence of these cracks indicates the weakness of the fabric and its fragility caused by the sever of the power of the laser beam. The effect of the engraving was not superficial on the fabric, as a large percentage of the fibres were fused compared to the untreated fibres as a result of the high laser energy, which means an increase in the depth of the engraving to reach depth of engraving approximately up to 75% of the surface of the fabric, as shown in the (Fig.10a).Carbon dioxide laser is one of the powerful lasers, so the energy level must be adjusted to avoid the consequences of sever thermal damage to the polymers [34]. The higher the amount of energy, the higher the melting degree of the surface of the fabric from partial fusion to full surface fusion [35]. When polyester fibres expose to high energy of laser beam are started to thermal degradation. The deterioration of polyester begins at a temperature higher than the melting point (260 C). Below that, the decomposition is slow due to the lack of oxygen below the melting point. Produced groups free of carboxylic acid and vinyl ester end-groups result of the random cleavage of the group (-$CH_2$-O-). The carbon monoxide, carbon dioxide or ethyne can then be produced result to the decomposition of the vinyl ester end-group [32]. (Fig. 10 d-c) The dissolution rate of the fibres varied according to the close and far of the distance laser beam. The solubility ratio of fibres and their fusion increased in step (0.1mm) more than (0.5mm). The clarity of the untreated fibres is greater for a sample (Fig. 10c) due to the passage of the laser beam at a far distance between the beam and the other, so the lower melting rate means less damage to the fibres and the material.

## 4. Conclusions

- The study revealed different effects of laser engraving technology on different fabrics. Laser parameters have a strong impact on different research fabrics. These effects were verified by detecting the mechanical properties of fabrics and colour change. Power and speed are the parameters that most affect the fabric's fibre. An increase in power damages the fabric; also, a low speed has the same effect on the fabric.
- The step parameter's impact on the research fabrics was significant. The measurement result for the colour change of fabric, the yellowing surface decreased with the increased speed at (500mm/s) and low power (20W), while the bright and clear engraving effect at step(0.1mm) for 100% Cotton and Cotton/polyester/ Lycra blended fabrics and at (0.1) step for 100%polyester fabric .
- Tensile strength values generally decrease for fabrics research. To be the best results for durability at quality, engrave at close laser ray' s distance for the variable (0.2mm) in both directions warp about (16.85%) and weft about (66.09%) for 100%cotton and about (64.08%) in warp and (69.25%) in weft direction for Cotton/polyester/ Lycra blended fabrics. For polyester fabric at (0.3mm/s), it decreases about (6. 56%) in warp and (12.39%) in the weft.
- The elongation and tear strength test results for optimum parameters on research fabric are acceptable. Crease angle is reduced for 100% cotton fabric and acceptable for 100%polyester fabric.
- SEM investigates the effect of parameters on the surface structure of fibres. Finally, five designs of the engraving technique were implemented on models of clothes of different fabrics. According to the results of the study, laser engraving technology can achieve not only unique aesthetic effects that serve the field of fashion design but also surpasses many traditional methods that require a waste of time and resources, which makes laser technology more environmentally friendly due to its flexibility in design control and the accuracy of choosing parameters.

## 5. Conflicts of interest

No potential conflict of interest was reported by the authors.

## 6. References


[1] Daukantienė V. Analysis of the sustainability aspects of fashion: a literature review. Textile Research Journal. 2023 Feb;93(3-4):991-1002.

[2] F. Unal, A. Yavas, O. Avinc, Sustainability in Textile Design with Laser Technology. In: Muthu S, Gardetti M (eds) Sustainability in the Textile and Apparel Industries. Sustainable Textiles: Production, Processing, Manufacturing & Chemistry. Springer, Cham. (2020); 263–287. https://doi.org/10.1007/978-3-030-37929-2_11.

[3] R. Nayak, R. Padhye, The use of laser in garment manufacturing: an overview, Fashion and textiles. (2016) ;3(1):1-6.

[4] ON. Hung, CK. Chan, CW. Kan, CW. Yuen. Microscopic study of the surface morphology of $CO_2$ laser-treated cotton and cotton/polyester blended fabric, Textile Research Journal. (2017);87(9):1107-20.

[5] SC. Singh, H. Zeng, C. Guo, W. Cai, Lasers: fundamentals, types, and operations. Nanomaterials: Processing and Characterization with Lasers, First Edition, Wiley-VCH Verlag GmbH & Co. KGaA. Weinheim, Germany. (2012);8-777

[6] J. Matthews, Textiles in three dimensions: an investigation into processes employing laser technology to form design-led three-dimensional textiles, Doctoral dissertation. Loughborough University. (2011);101-299.

[7] GX. Yuan, SX. Jiang, E. Newton, WM. Au, Application of laser engraving for sustainable fashion design, Research Journal of Textile and Apparel (2013)17(2):21-7.

[8] W. Zhang, An Exploratory Study of the Application of Laser Technology to Dress Design, Master dissertation. North Carolina State University.Raleigh, North Carolina. (2016);5-179

[9] Almasian A, Maleknia L, Mirjalili M, Chizarifard G, Application of Laser Treatment for Enhanced Dyeability and Comfort Properties of Bleached Cotton/Polyester, Asian Journal of Chemistry (2016) 28 (6):1229.

[10] G. Yuan, Laser Enhanced Sustainable Surface Treatment for Textile Design on Wool and Polyester Blended Fabric, College of Fashion and

Design, Donghua University, China. GARI (2018) 4 (4):1-9.

[11] Lamar TA. Laser Finishing of Textile Materials: Developments at ITMA 2019. Journal of Textile and Apparel, Technology and Management. 2019 Oct 29;1-5.

[12] Atwee T, Elshafei N, Mostafa HY, Bassyouni F. Application of Laser Technology to the Surface Treatments of Various Synthetic Textile Samples. *World Journal of Advances in Applied Physics and Mathematical Theories*. 2022;1:1-1.

[13] A. Sakib, T. Islam, S. Islam, M. Ahmed, S. Ali, Analysis the physical properties of laser fading on denim fabric, Journal of Textile Engineering. (2019) 5(6):288-90.

[14] JP. Dudeja, Laser application in apparel industry, Int. J. Adv. Sci. Technol. Eng. Manag. Sci. (2018) 4(9):1-5.

[15] Y. Angelova, S. Mežinska, L. Lazov, Innovative laser technology in textile industry: marking and engraving. In: Environment. Technologies. Resources, Proceedings of the International Scientific and Practical Conference (2017) 3: 15-21.

[16] CW. Kan, CW. Yuen, CW. Cheng, Technical study of the effect of $CO_2$ laser surface engraving on the colour properties of denim fabric, Colouration Technology (2010) 126(6):365-71.

[17] J. Sarkar, Khalil, A. Rahman, Technical study of the effect of $CO_2$ Laser surface engraving on the physical properties of denim fabric, International Conference of Mechanical Industrial and Materials Engineering (ICMIME), RUET, Rajshahi, Bangladesh (2015) 1-5. https://www.researchgate.net/publication/326914569

[18] Venkatraman PD. Carbon Dioxide Laser as a Sustainable Method for Producing a Pattern on Denim Fabric: Evaluation of Colour and Durability. Advance Research in Textile Engineering. 2022 Feb 22;7(1).

[19] YP. Angelova, Factors influencing the laser treatment of textile materials: An overview, Journal of Engineered Fibres and Fabrics. Sage (2020)15:1–16. DOI:10.1177/1558925020952803

[20] Marks& spencer P22, Investigative method of test crease recovery angle, Physical test methods for clothing (2001) 1-6.

[21] ASTM D76-93. Standard Specification for Tensile testing machines for Textile1. Revision Issued Annually. Annual book of ASTM standards (1997);07.01.

[22] ASTM D2261-96. Standard Test Method for Tearing Strength of Fabrics by the Tongue (Single Rip) Procedure (Constant-Rate-of-Extension Tensile Testing. Annual book of ASTM standards. (1997);70.1.

[23] American Association of Textile Chemists and Colourists. AATCC Evaluation procedure 1-Gray scale for colour change. (2002);82.2007: 377-465.

[24] ON. Hung, CK. Chan, CW. Kan, CW. Yuen, An analysis of some physical and chemical properties of $CO_2$ laser-treated cotton-based fabrics, Cellulose. (2017) 24(1):363-81. https://doi.org/10.1007/s10570-016-1090-z

[25] M. M. Aftan, M. A. Toma, A. H. Dalaf, E. Q. Abdullah, & H. K. Salih, Synthesis and characterization of new azo dyes based on thiazole and assess the biological and laser efficacy for them and study their dyeing application, Egyptian Journal of Chemistry, (2021). 64(6), 2903-2911.

[26] ON. Hung, A technological study of computer-aided laser finishing on cotton-based fabrics, Doctoral dissertation. Hong Kong Polytechnic University -Dissertations (2016)16-282

[27] ON. Hung, CW. Kan, A Study of $CO_2$ Laser Treatment on Colour Properties of Cotton-Based Fabrics, Coatings (2017) 7(8):131. http://dx.doi.org/10.3390/coatings7080131

[28] M. Jucienė, V. Urbelis, Ž. Juchnevičienė, L. Čepukonė, The effect of laser technological parameters on the colour and structure of denim fabric, Textile Research Journal (2014) 84(6):662-70. DOI: 10.1177/0040517513494256

[29] YL. Chow, to study the effect of laser irradiation on the properties of cotton fabric, Thesis submitted of Master. Pao Yue-kong Library, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong. PolyU Electronic Theses (2011) 28-161.

[30] YF. Chow, A. Chan, CW. Kan, Effect of $CO_2$ laser irradiation on the properties of cotton fabric, Textile Research Journal (2012) 82(12):1220-34. DOI: 10.1177/0040517511429609

[31] M. Štěpánková, J. Wiener, J. Dembický, Properties of cotton fabric after irradiation with infrared $CO_2$ laser, Fibres and Polymers (2014)15(10):2072-6. https://doi.org/10.1007/s12221-014-2072-0

[32] Mather RR, Wardman RH. The chemistry of textile fibres(2nd Editio). Royal Society of Chemistry; 2015 Nov 6;40-439.

[33] M. Montazer, S. J. Taheri, T. Harifi. Effect of laser $CO_2$ irradiation on various properties of polyester fabric: focus on dyeing, Journal of applied polymer science. (2012) 124(1):342-8. https://doi.org/10.1002/app.34930

[34] M. Esteves, H. Alonso, Effect of $CO_2$ laser radiation on surface properties of synthetic fibres, In: World Textile Conference, Raleigh, (2006)16 https://hdl.handle.net/1822/5398

[35] GX. Yuan, SX. Jiang, E. Newton, J. T. Fan, W. M. Au, Application of laser treatment for fashion design, J. of the Text. Inst. 103(1) (2012):48-54. https://doi.org/10.1080/00405000.2010.542311