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Surface Treatments using CO2 Lasers on a Variety of Synthetic Textiles

Tarek Atwee[1*], Nashwa Elshafei[2], Hamida Y Mostafa[3] and Fatma bassynouni[4]

[1]Physics Department, Faculty of Science, Damietta University, Egypt
[2]Ready Made Garments Faculty of applied Arts, Damietta University, Egypt
[3]Refining Department, Egyptian Petroleum Institute, 1 Ahmed El-Zomer Street, El-Zohour Region, Nasser City, Cairo, Egypt
[4]Department of Natural and medical products, National Research Center, Cairo, 12662, Egypt

***Corresponding author:** Tarek Atwee, Physics Department, Faculty of Science, Damietta University, 34511, Egypt, Tel: 07920610165, E-mail: atwee2001@yahoo.com

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Abstract

In this study, we investigated the effect of CO_2 laser energy on the surface of a variety of polyester textiles with thicknesses ranging from 2 to 3mm. To evaluate the laser action on the surface texture of this type of textile, the laser power was changed from 80 W to 120 W. A series of SEM images were taken with various incident laser powers. The rate of engraving operations increases as the incident laser power increases, and it is dependent on the thickness, chemical, and physical features of the irradiated fabric. According to the results of engraving samples. SEM photos demonstrate that laser treatment causes etching in all treated fabrics, even at a low incident laser power of 80W. In the marking, engraving, cutting, and welding processes, the CO_2 laser system is a suitable laser system for surface treating synthetic textile materials.

Keywords: Synthetic Textile; Laser Surface Treatments; CO_2 Laser; Undesirable Discoloration; Organic Fabric

Introduction

Presently, applications of laser systems for material processing and surface treatments are increasing rapidly and gaining much interest, due to several advantages such as the speed, accuracy, and flexibility of this innovative technology. Today all organic, polymers like textiles and leather, can be treated and processed by laser radiation. Synthetic textiles are suitable for laser surface treatment, both for marking, engraving, and welding because they are thermoplastic, while, organic fabrics such as cotton, wool, and flax do not melt under the heat action of laser radiation.

In the textile sector, laser technologies have replaced traditional dry surface modification procedures like as sandblasting and deliberate going, which could have been damaging. Conventional fabric modification processes are potentially hazardous and may be harmful for the environment. The laser technology enables us to modify the surface of fabrics without using water or toxic chemicals. Laser technology used in materials processing has gained much interest in the present time. Within a textile engineering context regarding synthetic fabrics. Several studies have demonstrated that laser technology can modify surface synthetic fabrics through laser beam interaction [1-8]. These studies have revealed that the interaction of laser beams can change the physical properties of synthetic fibers such as polyester (PET). By controlling laser parameters, such as the amount of energy applied on the fabric, the color changes on the surface affect its appearance without unacceptable damage to the material.

A number of laser treatments in the textile surface industry such as cleaning, ablation or engraving, marking, cutting, welding, sintering, three-dimensional scanning and many other laser materials processes have been successfully applied in the last two decades [9, 17]. Laser technology can also over many other processes in the textile industry such as using in decorative or analysis and identification marking of products, precise cutting, quality and clean joining by laser welding between both traditional materials and the newly developed ones. Because of the speed, accuracy, and flexibility of this innovative technology in materials processing the use of laser technology in the textile industry becomes more and more interesting for most fashion and textile world.

Laser irradiation of polymers can be used to generate a modification of the surface morphology at the irradiated regions. The normally smooth surface of synthetic fibers can be modified by this non-contacting technique to a regular role-like structure, which has a great effect on the general properties of the fiber]. Bahtiyari [18] has been investigated a new method for the modification of the properties of polyamide fabric, based on exposure to the output from a CO_2 laser. It was found that, after laser modification of polyamide fabric, the dyeability of fabric was increased significantly, while the bursting strength was decreased.

The treatment of textile polymers requires a laser with a wavelength that will be absorbed by the materials with low impulse energy and lower density processing than for materials processing. The laser employed in this study is a CO_2 laser with a wavelength of 10,600 nm that operates in the far-infrared (IR) spectrum; on the other hand, Excimer and YAG lasers produce output wavelengths in the ultraviolet (UV) spectrum.[19].

The CO_2 laser was the most efficient technique for marking fabrics, allowing for an acceptable level of fading at the lowest cost and energy levels. Other laser systems, such as YAG lasers (CTH:YAG / Ho:YAG), might be able to obtain the best outcomes by achieving the highest fading effect. However, the amount of electricity and money spent were needlessly high, resulting in inefficiency. These findings are echoed by Esteves & Alonso (2007) [20] who report CO_2 laser technology offers higher processing efficiency over other laser types. CO_2 lasers, according to Chow et al. (2011) [21], have advantages in textile processing due to their higher beam size and ease of operation. CO_2 is also a non-toxic and relatively inexpensive lasing medium. Due to their commercial availability and relatively moderate processing outputs, CO_2 lasers are the most used form of laser processing for textile applications in the fashion and textile industries. For these reasons, this research makes use of the CO_2 laser, also considering potential ease of knowledge transfer to laser systems already established in a commercial textile context. In the textile and fashion industry, it is common to combine laser treatment and pigment printing processes for creating special design and aesthetic effects.

It is important to know all the factors for a certain laser technical process such as laser marking or engraving or other surface modification processes to achieve good results with good accuracy. The characteristics of the irradiated material surface physical or chemical properties are essential for choosing the right laser power intensity for each laser process. The various factors, influencing the laser processing of natural and synthetic textile materials were presented and analyzed by Yordanka P Angelova [22].

In the present paper, we have investigated the effect of the CO_2 laser beam with different energies onto the surface of five selected samples with the same thickness approximately of synthetic textiles. Due to their characteristics, synthetic textile materials are considered the better choice for treating by CO_2 laser for marking, engraving, cutting, and welding processes. On the other hand, natural fibers like cotton, wool, and flax by laser surface treatment may result in undesirable discoloration because they do not melt A series of SEM images have been taken under different incident laser power to the change of the surface structure of irradiated synthetic samples at low and high incident laser energy. The influence effect of the absorbed laser energy transferred from the laser beam to the irradiated synthetic textile sample surface at different absorbed laser power was studied.

Laser Energy Density

Energy density is a metric for quantifying the amount of energy given to a substrate by a laser beam. The measurement, also known as laser fluence, takes into account many variables that can affect laser processing to produce a single number. This permits results to be replicated across a variety of laser systems with varying power outputs and velocity characteristics. Throughout this study, this was used as a metric. The impacts on the material substrate should be consistent as long as the total energy density supplied to the substrate stays constant. The overall energy density of a laser beam is used to calculate its density. It can be calculated as shown in Equation 1.

Total Energy = P x T(1.1)

Energy in its totality Where P is the laser's output power in Watts (W) and T is the time the focused laser beam will be in 'contact' with the substrate in seconds (s). The time will vary depending on the laser beam scanning velocity selected. For example, at a scanning speed of 700cm/s, traversing an area corresponding to the laser beam spot size will take $0.4x10^{-4}$ seconds (0.03cm). After determining total energy, the energy density of the laser beam can be computed using Equation 2.

Energy Density = Total Energy / Area(1.2)

Energy Density is a measure of how much energy is contained in a given amount of space. Where energy density is measured in J/cm2, the total energy is measured in Joules (J), and the area is measured in cm2. The 0.03 cm beam spot size utilized in this study corresponds to a beam area of $0.71x10^{-3}$ cm2.

Laser Ablation technology and applications

Presently, there are significant laser applications in different sectors of industry by focusing a laser beam onto the surface of certain substrate materials which produced what is called laser ablation. The ablation process by laser focusing occurs only when the energy absorbed by the material surface is sufficient to

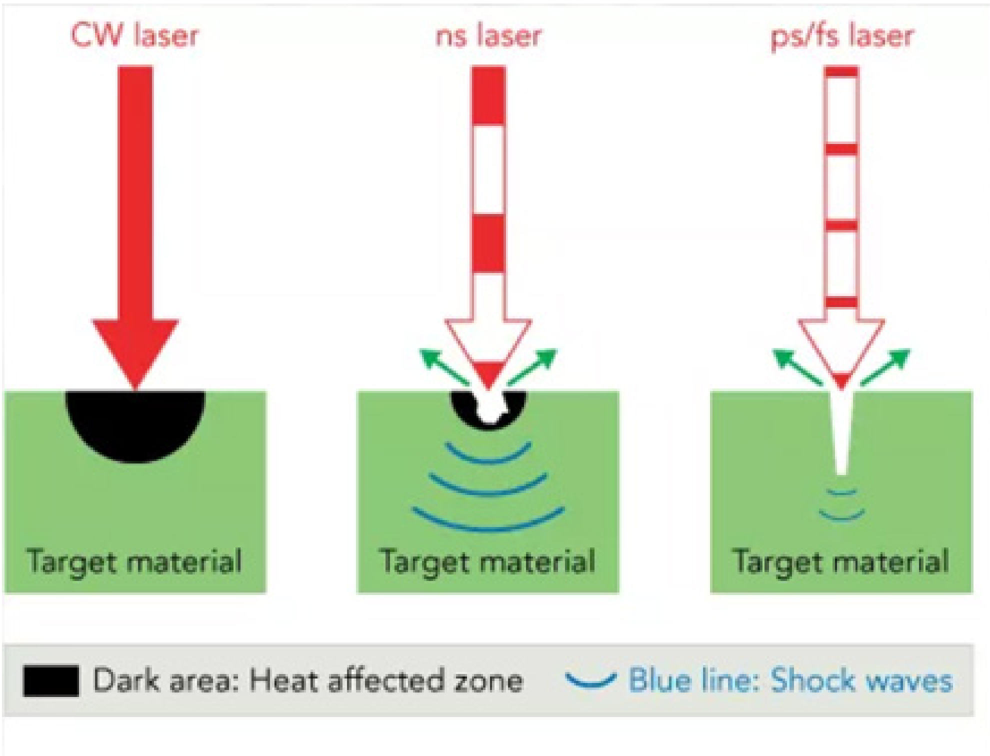


Figure 1: comparison between the heat affect zone in case of laser irradiation pulses: continuous wavelength (CW), Nanosecond (ns) and Picosecond (ps)/Femtosecond (fs) laser pulses

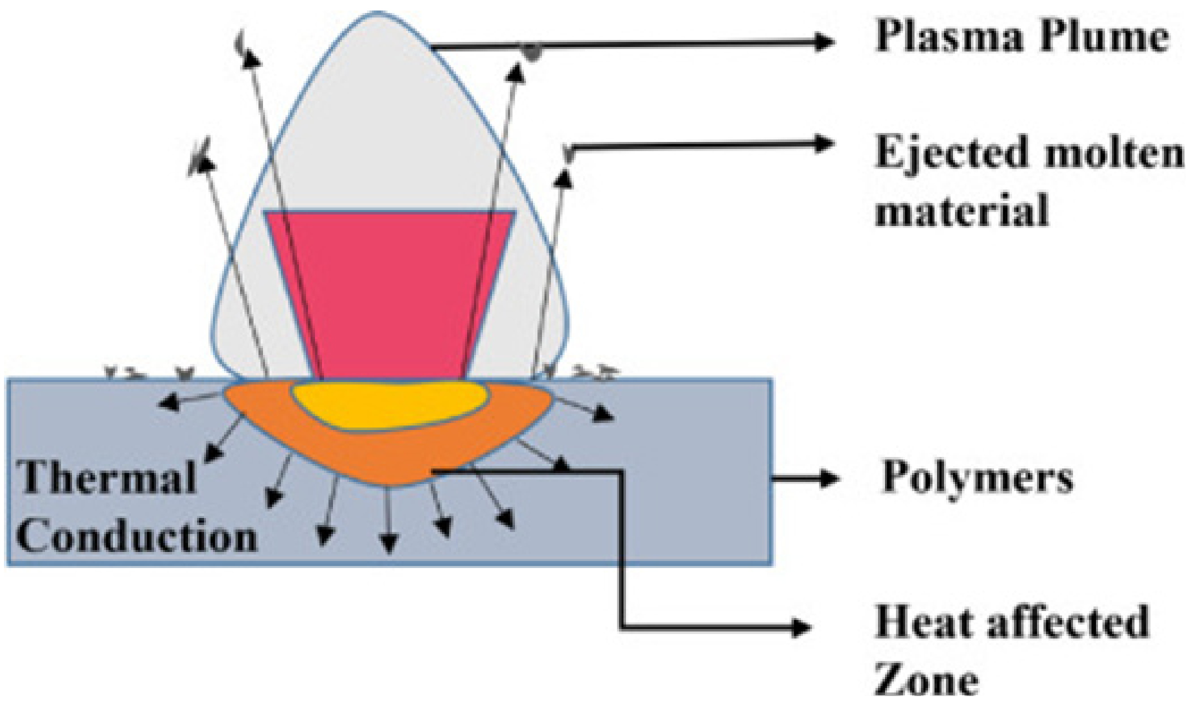


Figure 2: laser ablation process showed the ejected material atoms from the surface and Heat affected zone due to the laser irradiation of the surface

be melted and vaporized. The heating effect of the focused laser onto the substrate materials cause melting or vaporization of the materials, thus resulting in the removal of macroscopic materials from the substrate. AS known as the laser system can be classified according to the time scale of its pulse duration time. The laser is classified into millisecond (ms, 10^{-3}s), microsecond (μs, 10^{-6}s), nanosecond (ns, 10^{-9}s), Picosecond (ps, 10^{-12}s), and femtosecond (fs, 10^{-15}) laser.

The pulse duration determines the ablation process's characteristic — short or ultra-short laser ablation — as seen in Figure 1. The ablation mechanism, accuracy, and precision of the features are all influenced by the timescale of the laser pulse duration. Chopping a continuous wave laser beam produces millisecond and microsecond lasers. The ablation of polymers by lengthy pulses has been reported to leave indications of molten materials and carbonization of the walls of the ablated structures. In terms of high precision, high material removal rate, and minimum thermal damage, ultrashort laser pulses with timeframes of femtoseconds or picoseconds outperform longer laser pulses. Two processes are responsible for it: thermal diffusion and nonlinear absorption. On the ultrashort timescale, there is insufficient time to transfer the heat energy from the excited electrons to the lattice, resulting in little thermal damage.

Mechanisms of laser ablation

Across laser processing technologies such as laser beam milling, high-precision drilling, and laser cutting, the general process of laser ablation is consistent. As seen in Fig. 2, ablation is a mix of vaporization and melt ejection. When a focused beam of laser radiation impacts a surface, hence the energetic laser photons will excite the electrons in the substrate target material [23]. Beer Lambert's law [23, 24] predicts that this excitation will result in the creation of heat by absorbed photon energy. The wavelength of energy absorbed is proportional to the depth of the materials and the intensity of the source of light, according to Beer Lambert's law. The heating effects enable the material to melt or vaporize, allowing macroscopic materials to be removed from the substrate. The development of a plasma plume occurs when a solid becomes a gas.

The transition from one phase to the next occurs through a succession of steps. The initial heat generated by the laser beams' absorbance causes a melt pool to form at the laser-substrate contact zone. Due to the input pulses, the temperature rises even more, and the melt pool reaches the vaporization condition [25]. Throughout vaporization, high pressure is formed, also known as return pressure, which pushes molten components out of the pool where they are expelled [26]. Because of its re-deposition on the substrate or in the contact zone, the ejected material is a problem [27, 28]. The liquid achieves an explosive liquid-vapor phase transition stage by raising the temperature at the beam contact zone [29, 30]. The aforementioned mechanism is known as a "burst" and is typically shown throughout ablation with long-pulsed lasers. The fluid movements and vapor characteristics are quite complex in this process, and re-solidification of the molten material causes geometrical alterations in the ablated structures. The ablation mechanism can be chemical, thermal, or a mixture of both, depending on the laser and material variables such as fluence, absorption coefficient, and reflectivity, wavelength, and pulse width. The intensity of UV radiation emission sources causes the covalent compounds in the polymer to shatter, resulting in photodegradation ablation. The electronic excitation caused by UV photons is thermalized in photothermal ablation, resulting in the breakdown of polymer bonds. Various studies have attempted to explain the dynamics at the laser-material interaction area by assuming one mechanism prevails and then modeling the dominating process [31-32]. All of these methods are reliant on a unique combination of light and material qualities. As a result, certain significant phenomena must be considered when researching the laser-material interaction. The kind and degree of light energy absorption, as well as the time scale of the laser pulse, are examples of these phenomena. The absorption is linear and follows Beer Lambert's law at normal intensities. Heat will transfer to the lattice when electrons are activated due to photon absorption from the incident laser beam onto the target surface, resulting in melting and vaporisation at the irradiated target's surface. However, absorption becomes nonlinear and intensity-dependent over ultrashort timescales. Due to a significant absorption coefficient and high intensities, the material's bound electrons can be immediately ionised. As a result, characterizing the laser in use and predicting the process that occurs at the laser-material interaction zone is critical [33]. All of these methods are reliant on a unique combination of light and material qualities.

Experimental techniques

As shown in Figure 2.1(a) and (b) we present the schematic diagram of CO_2 laser system which is applying for laser engraving or cutting of fabric textiles and surface modification or treatment technology. The laser engraving process was conducted with a CO_2 source laser engraving machine (2000 Laser,

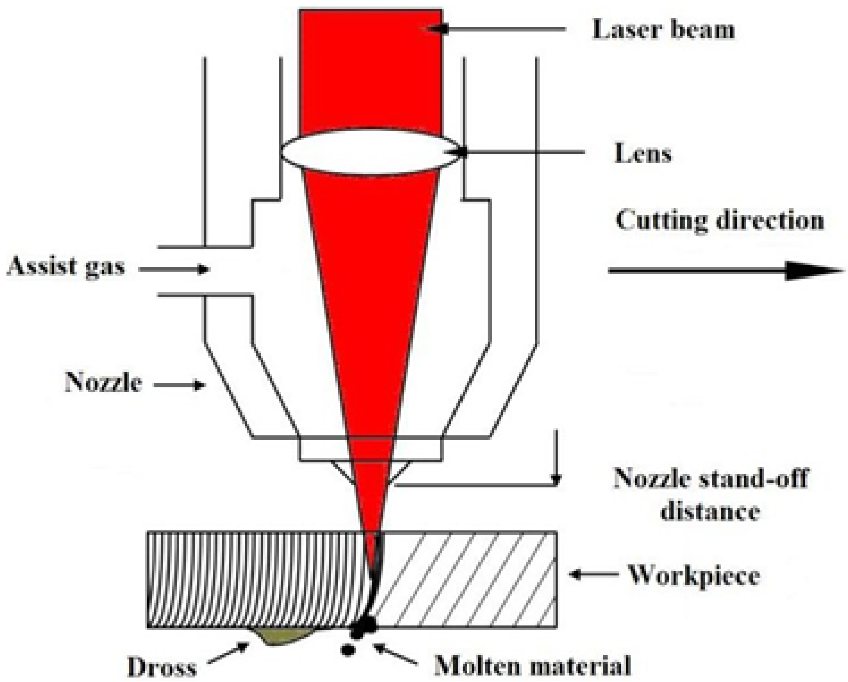


Figure 2.1 (a): Schematic diagram of CO_2 Laser engraving and Cutting system

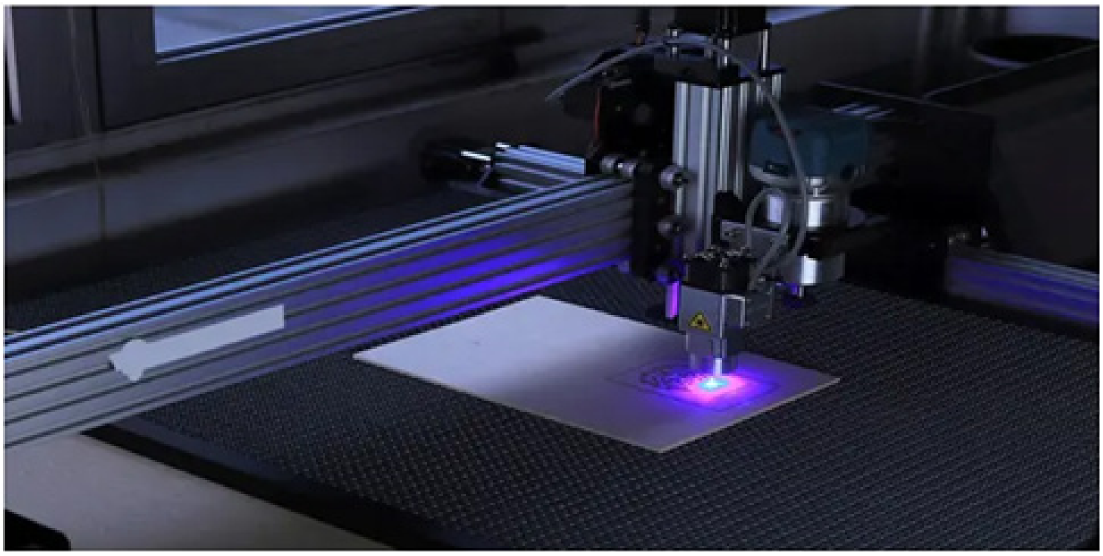


Figure 2.1 (b): Laser Engraving and cutting Machine Specifications

Table 1:

Specification of the laser engraving machine
Manufacturer/model: 2000 Laser, Multicam
Laser frequency: 10000 Hz
Laser medium: CO_2
Wavelength: 10.6 μm
Wave mode: Pulsed

Multicam, America) in Furniture Technology Center in Damietta with specifications are shown in Table 1.

The beam gun's intensity is regulated utilising a mechanical device designed to modify the area of the focused CO_2 laser point onto the surface of an irradiated textile sample. The optical device is utilised to focus the laser beam according to the power intensity that has been chosen as illustrated in Figure 2.1 (a) and (b) (b).

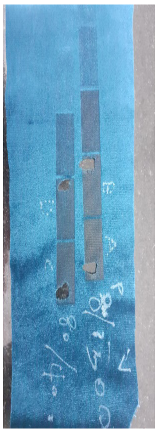
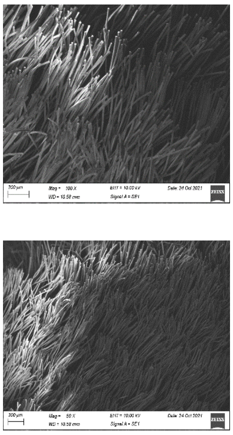
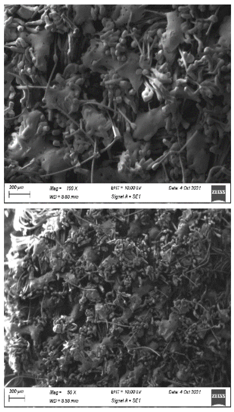
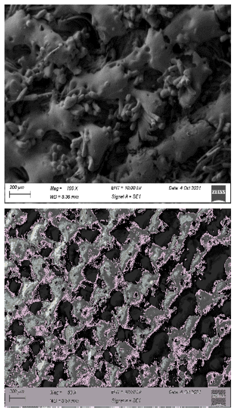
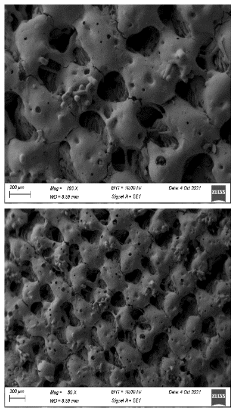
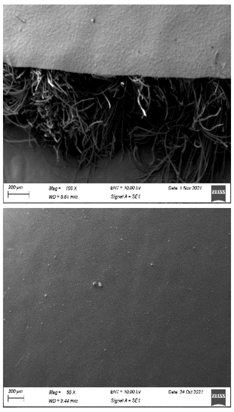
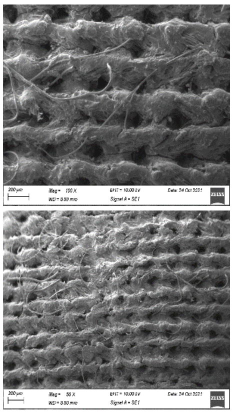
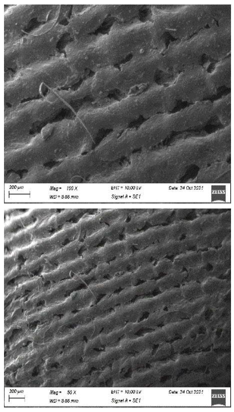
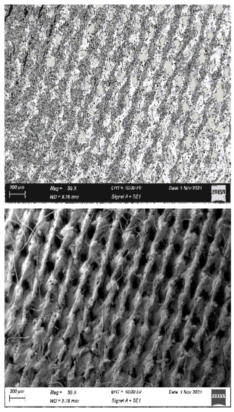
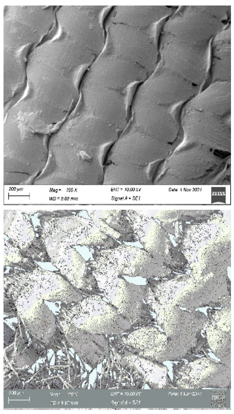
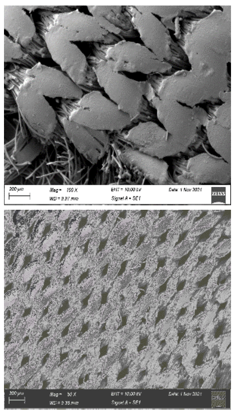
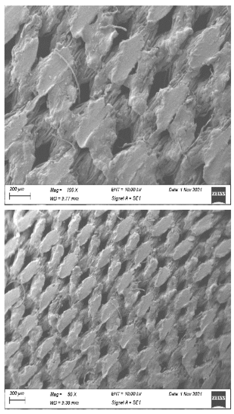
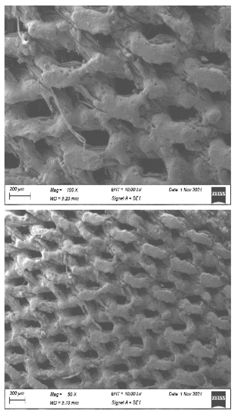
Because of changing of the laser interaction time onto the irradiated spot area, it is impossible to guarantee that the laser will always have the same effect on the textile. For long time dour laser irradiation onto the spot area, it well be cause an increase in heat at effective zone. Also, when the laser power or pulse duration time are increased, that means a stronger reaction between the laser beam and the surface of irradiated textile will be observed. So, we must be taken into account all these parameter when we selecting the laser beam incident energy to avoid a thermal damage to the irradiated sample.

Results and Discussion

In the present study, we have selected five sample of synthetic textile which have approximately the same thickness and influence of incident of CO_2 laser power varied from 80W to 120W onto the morphology of the surface of such kind of textiles have been studied. A series of SEM images as shown in Figure (3.1) were recorded using a scanning electron microscope model [Zeiss -SEM, (EVO 10) with electron source tungsten filament, Germany) at 10kv, with a magnification of 50x (300μm) and 100x (200 μm), and all samples were coated with gold] for all irradiated samples before and after laser irradiation process for every value of the incident CO_2 Laser power. AS shown from SEM images, for a lower incident laser power from 40W and 60 W no change happened on the surface morphology. While as the incident laser power was increased to 80W the surface engraving process becomes notable and changes of the surface morphology for all irradiated samples are occurred compared to the un- irradiated original one.

Thermal treatment of textile materials, as is well known, induces changes in micro and macrostructure. Because heat is transferred to the treated surface area during the laser irradiation process, it is critical to evaluate the irradiated surface's basic thermal physical characteristics, such as thermal conductivity, specific heat capacity, melting point, and diffusivity.

On the global market today, a wide range of laser sources and laser systems with various characteristics and applications are available. As a result, it is vital to choose a laser system with a good laser beam quality and a wavelength that will be best absorbed by the individual material in each circumstance. Polymers used to treat textiles must have a wavelength that is in the

Name	Optical Image	No irradiated laser Power	Low laser power (80 watts)	Medium laser power (100 watts)	High laser power (120 watts)
velour fabric					
Leather fabric					
Lame fabric					

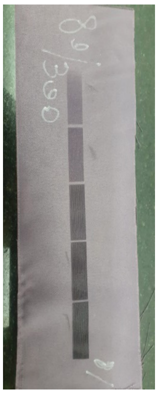
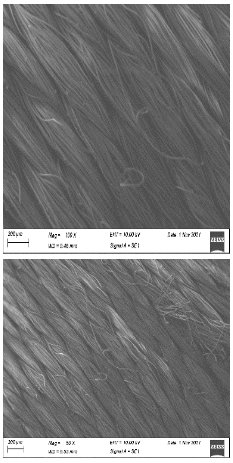
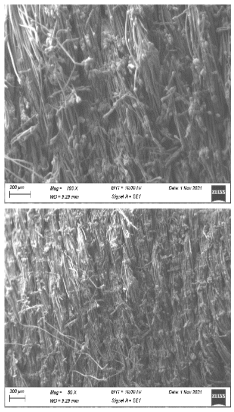
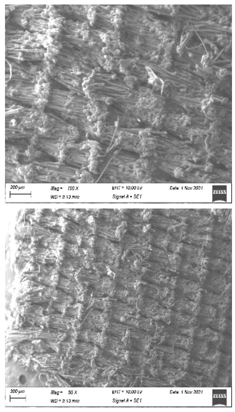
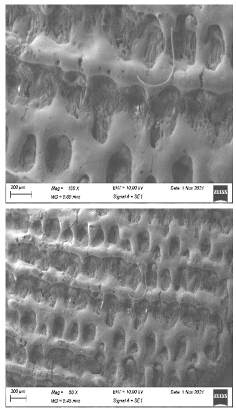
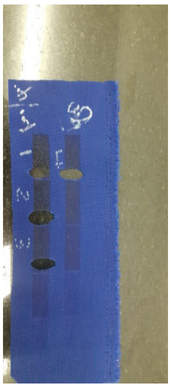
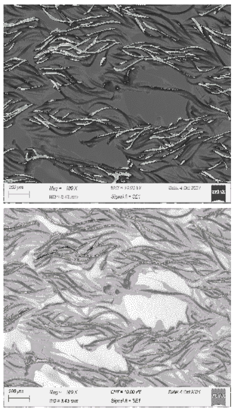
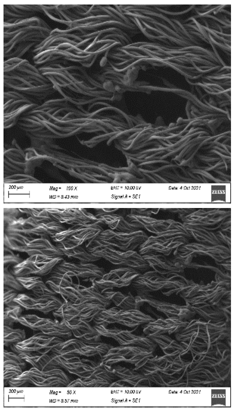
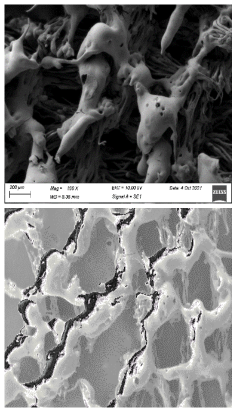
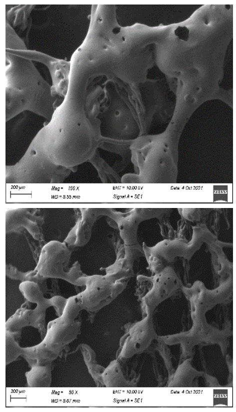
Name	Optical Image	No irradiated laser Power	Low laser power (80 watts)	Medium laser power (100 watts)	High laser power (120 watts)
Satin fabric					
jersey fabric					

Figure 3.1: SEM Images showed the effect of CO2 incident Laser Power on the surface of five different synthetic Textile samples; three different laser Power values of 1- Low power at 80 watts, 2- Medium power at 100 watts, and 3- High power at 120 watts, with two different magnification values of 100X and 200X.

infrared range. Such a CO_2 Laser System will be absorbed by the material surface with a lower impulse energy and power density than a metal processing system. The key factor that determines the surface morphology of laser-irradiated samples is the surface density power qs, which is given by the following formula.

$$q_s = \frac{P}{S} = \frac{4P}{\pi d^2}, W.m^2 \qquad (3.1)$$

Where: P is the average laser source power and S is the area of the working spot is determined by $S=d^2/4$, d is the diameter of the working spot focusing onto the surface of the irradiated sample. The surface power density is directly proportional to the average laser source P and inversely proportional to the incident laser beam's spot area, as indicated in Equation. Because most laser systems have an average power specified for each laser source that cannot be changed, the optimization of this parameter will be determined by the laser beam's focal surface area. The diameter of the laser beam's focusing spot changes, which affects the amount of surface power density absorbed by the sample and, in turn, the degree of engraving that occurs on the irradiated surface. The surface power density qs must be estimated for each case for optimum laser material processes, notably for textile laser engraving or marking, and to obtain a visible contrast making onto the irradiated surface without breaking the textile fiber. The rate of marking is faster than the rate of cutting for the same textile material. When the laser beam arm moves quicker, the time it takes for the laser to make contact with the surface is shorter, and the quantity of energy absorbed by the irradiation spot area of the materials is smaller, and vice versa. So, understanding the material's physical and chemical properties prior to laser treatment or processing, as well as the mechanism of energy transfer when the laser interacts with matter and how the absorbed energy is transformed by a specific material, is critical for a good surface treatment or modification. The number of repetitions N, which specifies the number of repeats of the laser beam for the marking, engraving, or cutting process, is also crucial in laser material processing or laser engraving. or a better laser engraving procedure, it was advised that lower laser power be employed. The primary distinction between marking and engraving is that the laser action creates depth on the surface of the irradiated substance. During laser marking, the laser effect alters the materials' properties or appearance, primarily by discoloration (fading) or coloration (carbonization). The laser beam effect on the irradiated material will be stronger in the engraving process than in the marking process, and the laser action will remove a portion of the irradiated surface material. The rate of laser engraving increases as the incident laser power is increased until a particular value of the targeted power is reached after the cutting process for irradiated fabric cloth begins. The cutting process for all irradiated synthetic textile samples occurred at the laser incident, as seen in SEM pictures in Figure (3.1).

As previously stated, by adjusting laser parameters such as the amount of energy supplied to the fabric, color changes were induced on the surface, altering its look without causing unacceptable material damage. The alteration of the surface morphology at the irradiated regions can be achieved by laser irradiation of polymers. According to the researcher's previous work, fabric hand properties show that laser therapy can successfully affect several features of materials such as stiffness, durability, softness, drapability, and wrinkle recovery. The draping coefficient of laser-treated materials was found to be high following the laser treatment process, implying that the fabric's drapability decreases after laser treatment [34]. On the other hand, the stiffness of laser-treated cotton/polyester mixed fabrics suggests that they are stiffer and more difficult to drape. The silhouette of a garment can be altered in response to changing fashion trends by employing laser treatment on materials since the quality of the fabric used impacts the aesthetic performance of a garment. After laser treatment, it was discovered that 100% cotton-woven garments had better drapability and wrinkle repair than other materials. One of cotton's major flaws as a textile material is its proclivity to fold and wrinkle. As a result, they have a wrinkle-free appearance. On the other hand, these finishing methods are typically linked to resins that generate formaldehyde, which is detrimental to human health. Laser treatment of fabrics could assist to reduce the use of toxic chemicals in finishing operations. This can help reduce not just the number of chemicals and derivatives used, but also the amount of water used and the danger of negative health impacts. The stiffness of the cotton/polyester blended textiles were found to be much increased after laser irradiation. The lack of rigidity in the cloth makes the tailoring procedure more difficult. As a result of the rapid distortion, cutting the textiles becomes more difficult, and seam puckers occur more frequently throughout the sewing process. If the laser processing factors are well controlled, laser treatment may be able to eliminate such difficulties in some flexible materials during the production stage, as shown. Laser textile treatments and laser textile surface modification are now very essential flexible tool techniques in the fashion industry, because to the vast range of laser systems accessible with wavelengths ranging from UV to infrared. A laser cuts individual patterns in fabrics produces patterns and improves final clothing or accessories with accuracy and flexibility. The laser beam dissolves synthetic textiles when cutting them, resulting in a significant reduction in lint production. The ultimate result is a tidy, well-sealed set of edges. With laser engraving, you may get a more tangible tactile impact. As a result, end goods can be fine-tuned to perfection. Using laser technology for processing, labeling, engraving, and cutting garments has become a more exciting and enticing option. As a result, before using laser technology on any target sample, it is vital to understand all aspects of the laser technology processes and how they should be combined with physical features. In addition, the concepts of laser-matter interaction and laser ablation mechanisms for all types of laser pulses are critical to the end results.

Conclusion

Choosing the suitable laser equipment for textile laser treatment operations requires an understanding of the physical qualities and features of the materials. CO_2 laser was used to treat synthetic textile materials, not only for marking and engraving, but also for cutting and welding. Natural fibers such as cotton, wool, and flax, on the other hand, may be discolored by laser treatment because they do not melt under the heat action of the laser beam. As a result, understanding all aspects of laser technology processes, as well as their optimal interaction with the physical features and qualities of laser-irradiated materials, is critical for the final results. As a result, the laser source power and the technological process speed, as well as their precise modification according to the processed material, are critical for producing excellent laser processing results. This article provided and studied the different parameters that influence the laser processing of natural and synthetic textile materials. The factors, which were classified into four groups, were identified. Their interconnections and interdependencies were studied and organized. The impact of the laser beam on the cloth caused the fibers of the threads used to produce the textiles to melt locally. The surface of the knitted or woven cloth was altered even at low laser power. Individual threads became less likely to become loose and protrude from within the product as a result of this. The likelihood of the threads becoming entangled and forming unwanted fuzz, popularly known as pilling, was reduced as a result. Excessive laser power induced excessive melting of the projecting fibers, rendering the textile product unfit for use due to the negative aesthetic effects. The laser ablation process can be used to reduce any pilling that has appeared on the fabric's surface, as well as to treat and change any textile. This process offers various advantages over other popular chemical methods, including the absence of harmful residues, ease of control over the heat source, and minimal energy requirements for pill removal as compared to other methods. The engraving CO_2 Laser powers used in this study ranged from 60 to 100 watts, and the maximum engraving power for each type of sample must be determined.

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Data Availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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