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Application of Laser Technology to the Surface Treatments of Various Synthetic Textile Samples

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Abstract

In this study, we investigated the effect of CO2 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 made of knitted samples treated with different 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. When it comes to selecting the correct laser, the material's features are critical. The CO2 laser was used to effectively mark and engrave synthetic textile fabrics, as well as cut and weld them. So the CO2 laser system is a suitable laser system for the surface treatment of synthetic textile materials in the marking, engraving, cutting, and welding operation

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

Background

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In the textile business, laser technologies have largely superseded traditional dry surface alteration procedures such as sandblasting and intentional aging, which can be damaging. Traditional fabric modification techniques can be dangerous and detrimental to the environment.

The use of laser technology allows fabric surfaces to be modified without the use of water and, in many cases, without the use of harmful chemicals. Lasers can be used to engrave or brand textile materials, identify or add product information, create a distinctive logo, and even prevent theft [1].

The ability to combine multiple operations in one production cycle, such as surface modification, cutting, engraving, and marking, is an undeniable benefit of adopting laser technology in the garment sector. When compared to traditional denim cutting, embossing, engraving, and fading techniques, laser alteration is a cost-effective option. There is a low risk of product damage, and no additional consumables are required. When a laser is used to treat the surfaces of fabrics, unlike chemical methods, no harmful byproducts are produced [2]. A laser beam, unlike mechanical instruments, does not wear out after repeated usage, allowing for higher precision. The treated cloth will not tear if the treated surface is physically melted. Lasers can cure practically any textile with no risk of contamination. Fabrics also can be treated with lasers without losing their hand. It has no effect on the fabric's stiffness, softness, smoothness, or ease of draping, and has no effect on the aesthetic look of clothing [3]. They can even be used to connect textiles with wearable electronics [4]. It is possible to accurately treat the surface while keeping a zone of low heat influence on the fabric structure because of the stability and ease of usage of the laser source [5]. The wettability of the textile can also be altered by laser or plasma ablation [6].

Laser irradiation of polymers can be used to generate a modification of the surface morphology in 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 [7], has investigated a new method for the modification of the properties of polyamide fabric, based on exposure to the output from a CO2 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 CO2 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 [8].

The CO2 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) [9] who report CO2 laser technology offers higher processing efficiency over other laser types. CO2 lasers, according to Chow et al. (2011) [10], have advantages in textile processing due to their higher beam size and ease of operation. CO2 is also a non-toxic and relatively inexpensive lasing medium. Due to their commercial availability and relatively moderate processing outputs, CO2 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 CO2 laser, also considering the 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 designs and aesthetic effects.

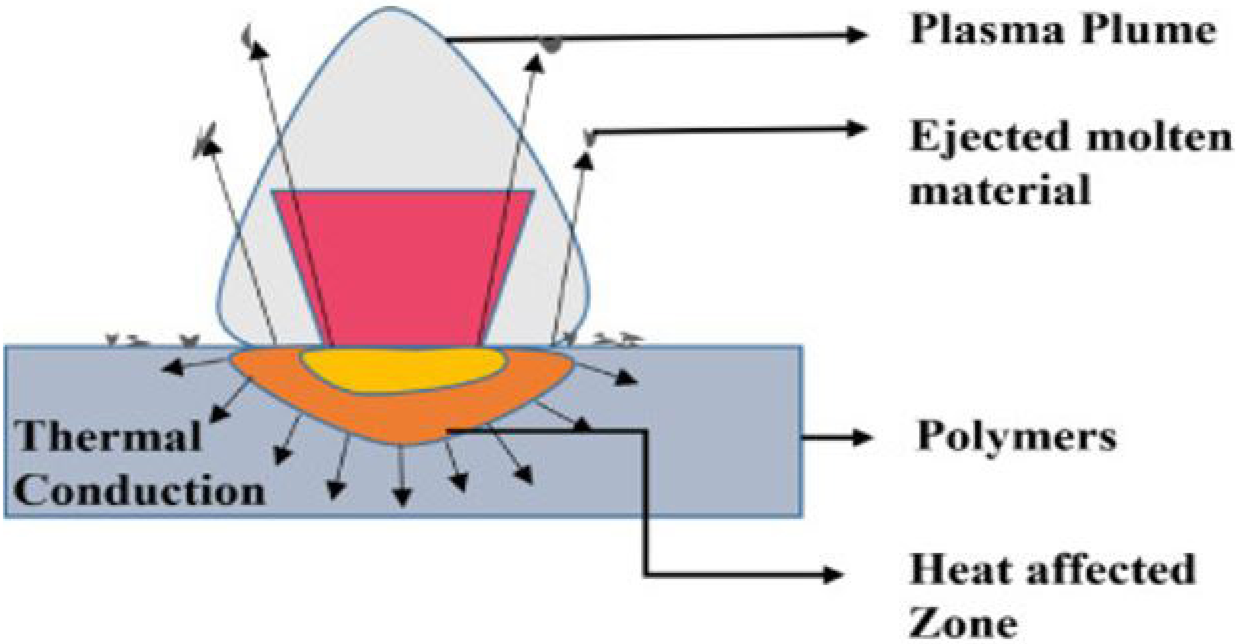


Figure 1: laser ablation process showed the ejected material atoms from the surface and Heat affected zone due to the laser irradiation of the surface

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. 1, 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 [11]. Beer Lambert's law [12] 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 [13]. Throughout vaporization, high pressure is formed, also known as return pressure, which pushes molten components out of the pool where they are expelled [14]. Because of its re-deposition on the substrate or in the contact zone, the ejected material is a problem [15, 16]. The liquid achieves an explosive liquid-vapor phase transition stage by raising the temperature at the beam contact zone [17, 18]. 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 laser power, absorption coefficient, reflectivity wavelength, and pulse width.

To get good results with good accuracy, it is necessary to understand all of the parameters for a certain laser technical procedure, such as laser marking or engraving, or other surface modification techniques. The physical or chemical qualities of the irradiated material's surface are critical for selecting the appropriate laser power intensity for each laser procedure. The various factors, influencing the laser processing of natural and synthetic textile materials were presented and analyzed by Yordanka P Angelova [19].

In the present paper, we have investigated the effect of the CO2 laser beam with different energies on 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 CO2 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

Experimental Work and Techniques

Laser Irradiated textile Materials

We use laser engraving techniques as a sustainable surface treatment approach for a variety of synthetic textile samples in this experiment, with varying incoming laser power from 80W to 120W and laser beam velocity at 100 m/s and 200 m/s. Knitted synthetic selected samples from velour, leather, lame, satin, and jersey fabrics with thicknesses ranging from 3 to4 mm were used for this investigation. The laser beam may melt, vaporize, and etch the textile surface without the need of water or chemicals in a contactless process. After laser treatment, unique pattern appearances on blended cloth with shade changing effects were achieved using a computer-aided design technique.

Because the length of interaction at the site may be prolonged, causing an increase in heat at the affective zone, it is impossible to ensure that the laser will always have the same impact on the cloth. When the radiation intensity and pulse duration are increased, greater interaction between the laser beam and the textile is noticed. When choosing the parameters for laser beam radiation, which can produce observable thermal damage to the sample, beginning with surface bronzing and melting, these very complicated phenomena should be taken into account. All treatments were carried out in a normal air environment. All samples were coated with gold] for all irradiated samples before and after the laser irradiation process for every value of the incident CO2 Laser power. A scanning electron microscope model [Zeiss -SEM, (EVO 10) with electron source tungsten filament, Germany] operating at 10kv and magnifications of 50x (300m) and 100x (200m) was used to take a series of SEM images for all irradiated samples before and after the laser irradiation process for each value of the incident CO2 Laser power.

CO_2 Laser cutting and Engraving Machine

There are various applications of laser in the apparel business as a brand-new method. Many garment businesses, fabric production units, and other textile and leather industries are now using laser engraving and cutting technology

We exhibit the schematic diagram of the CO2 laser system in Fig. 2.(a) , (b) and (c), which is used for laser engraving or cutting of fabric textiles, as well as surface modification or treatment technology. The laser engraving surface of the selected synthetic samples was carried out in the Furniture Technology Center in Damietta, Furniture City, Damietta, Egypt, using a CO2 source laser engraving equipment (2000 Laser, Multicam, America). The specifications of CO_2 laser machine are given in Table 1.

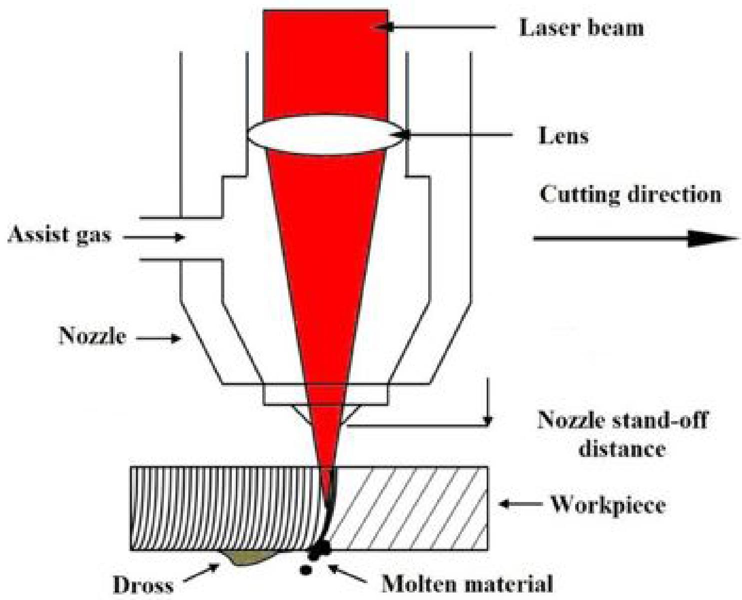


Figure 2 (a): Schematic diagram of CO2 Laser engraving and cutting system

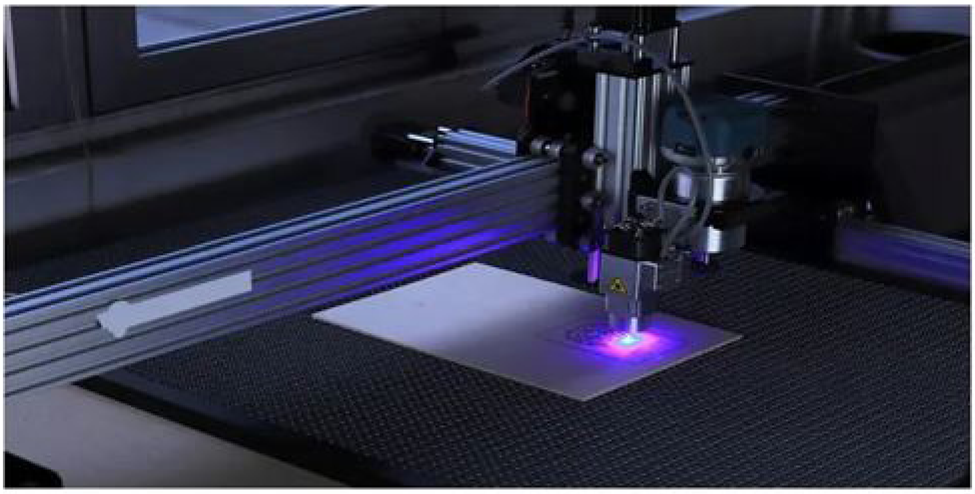


Figure 2 (b): shows the image of laser beam spot area with the mechanical device designed to modify the focused area of CO_2 onto the irradiated textile sample

The beam gun's intensity is regulated utilizing a mechanical device designed to modify the area of the focused CO2 laser point onto the surface of an irradiated textile sample. The optical device is utilized to focus the laser beam according to the power intensity that has been chosen as illustrated in Figure 2 (a) and (b).

Figure 2 (c): Shows CO_2 Laser Engraving and Cutting Machine

Table 1: The specification of CO_2 laser machine

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

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 infrared range

Results and Discussion

Laser technology is gaining popularity as a physical treatment approach in the textile finishing process, particularly for surface modification, which is traditionally done through chemical finishing. The use of a laser-controlled by a computer can be used to modify various materials such as polymers, woods, and metals, changing the physical and chemical properties of the material surface. When compared to untreated fiber, laser irradiation is known to induce more weak places on the fiber surface in terms of both tensile strength and extensibility. The laser can alter fiber properties in the dye take-up process by causing a laser-induced ripple structure on the fiber surface, hence improving the dyeing performance of laser-treated polymer fibers. It can also aid in the enhancement of denim's visual appeal.

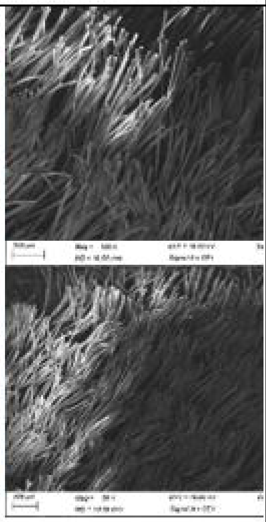
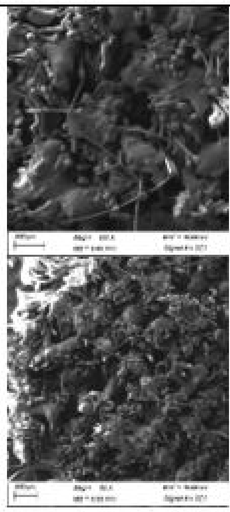
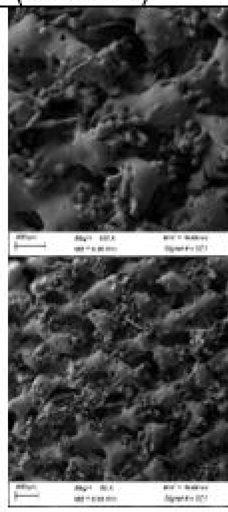
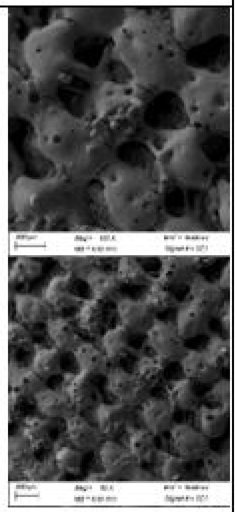
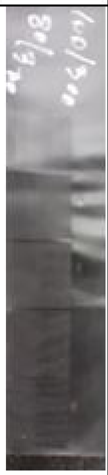
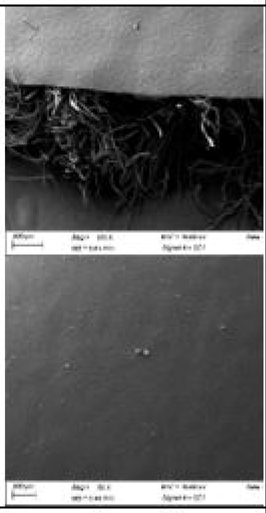
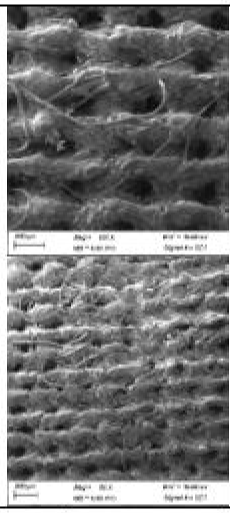
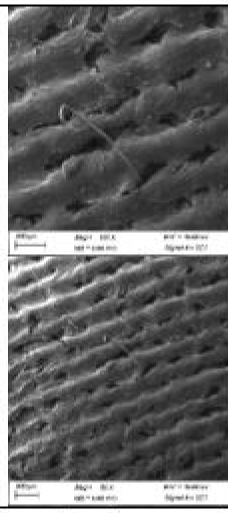
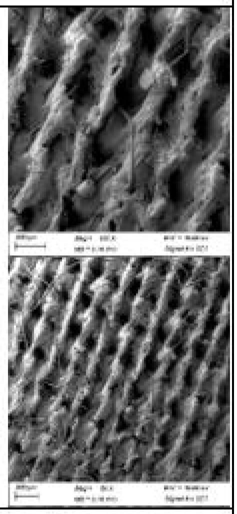
In the present study, we have selected five samples of synthetic textiles which have approximately the same thickness and influence of incident of CO_2 laser power varied from 80W to 120W onto the morphology of the surface of such kinds of textiles have been studied. The selected knitted samples are Velour, leather, Lame, Satin, and Jersey fabrics textile. A series of SEM images as shown in Fig. (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 the 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 in 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.

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 q_s which is given by the following formula.

$$q_s=\frac{P}{S}=\frac{4P}{\pi d^2}, W.m^2 \qquad (1)$$

Where: P is the average laser source power and S is the area of the working spot is determined by S=d2/4, 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 q_s 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. For 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 Fig. (3).

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					
Name	Optical Image	No irradiated laser power	Low laser power (80W)	Medium laser power (100 w)	High laser power (120 W)

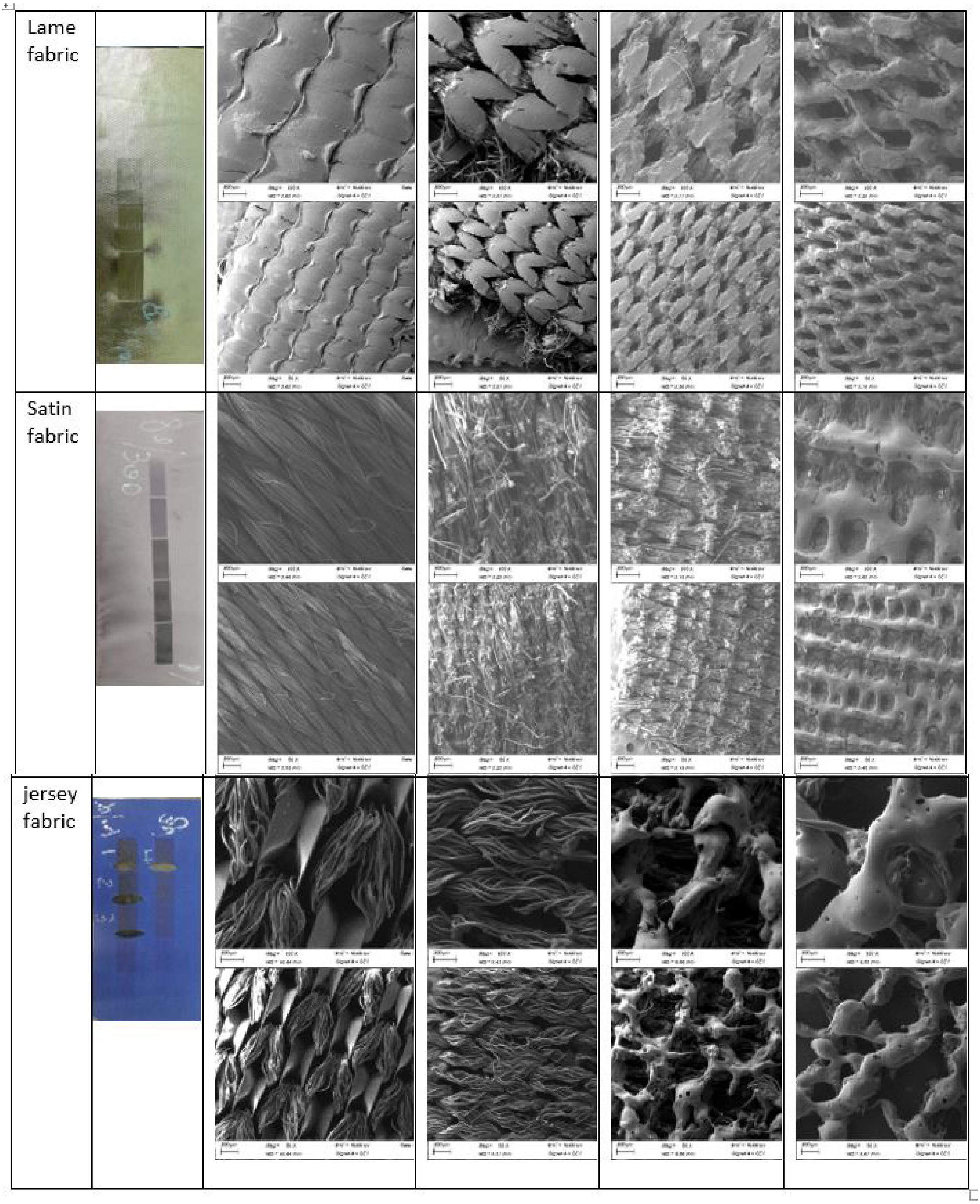


Figure 3: SEM Images showed the effect of CO2 incident Laser Power on the surface of five different synthetic Textile samples; three different laser Power values of 1- Low power at 80 watts, 2- Medium power at 100 watts, and 3- High power at 120 watts, with two different magnification values of 100X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

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. Fabric hand qualities reveal that laser therapy can successfully influence numerous features of materials like as stiffness, durability, softness, drapability, and wrinkle healing, according to the researcher's past work. Because the quality of the fabric used affects the aesthetic performance of a garment, laser treatment on materials can be utilized to alter the silhouette of a garment in response to changing fashion trends. Following laser treatment, it was observed that clothes made of 100 percent cotton weaved had superior drapability and wrinkle healing than those made of other materials. Cotton's inclination to fold and wrinkle is one of its fundamental weaknesses as a textile material. As a result, they appear to be wrinkle-free. These finishing procedures, on the other hand, are frequently associated with resins that produce formaldehyde, which is harmful 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 was 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 of 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

Understanding the physical properties and features of the materials is required when selecting the appropriate laser equipment for textile laser treatment operations. Synthetic textile materials were treated with a CO2 laser for not only marking and engraving but also cutting and welding. Natural fibers like cotton, wool, and flax, on the other hand, maybe discolored by laser therapy since they do not melt when exposed to the laser beam's heat. As a result, mastering all aspects of laser technology processes, as well as their appropriate interaction with the physical properties and characteristics of laser-irradiated materials, is essential for achieving the best possible results. As a result, for optimal laser processing outcomes, the laser source power, and technological process speed, as well as their precise change according to the processed material, are crucial. The fibers of the threads used to make the textiles melted locally as a result of the laser beam's impact on the cloth. Even at modest laser power, the surface of the knitted or woven textile was transformed. As a result, individual threads were less likely to become loose and protrude from within the product. As a result, the chances of the threads becoming entangled and generating unsightly fuzz, often known as pilling, were reduced. Due to the unfavorable aesthetic impacts of excessive laser power, significant melting of the projecting fibers occurred, rendering the textile product unfit for use. The laser ablation procedure can be used to treat and transform any textile, as well as to minimize any pilling that has appeared on the fabric's surface. In comparison to other popular chemical procedures, this method has a number of advantages, including the absence of toxic residues, ease of control over the heat source, and low energy requirements for pill removal. The CO2 laser engraving powers employed in this investigation ranged from 60 to 100 watts, with the greatest engraving power being 100 watts.

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Declaration of conflicting Interests

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Conflicts of Interest

The authors declare no conflict of interest.

Data Availability

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

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