Effects of Co2 Laser Cutting Technique on Bending Properties of Cotton and Cotton Blended Fabrics

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Abstract:
Since laser cutting technology is more accurate, quick, flexible, and easy to use than other traditional cutting methods, it is frequently utilized in the textile industry to create patterns and designs. The study has been focused on the behavior of bending property and its effect on fabrics which have been cut by applied carbon dioxide laser (Co2) as the most common using in clothing applications which applied by using cutting technique on the fabrics were produced as (100% cotton, 99% cotton/1%lycra, 98% cotton/ 2%lycra, 74%Cotton/25%Polyester/1%Lycra and 78% cotton/ 21% Polyester/ 1% Lycra). The Co2 laser parameters used were power (40, 50, 70 & 90 w) and speed (50,100,120 & 150 mm/s). These parameters applied with a constant height of the laser head above the surface of the material at 0.6mm.
In this paper, the effects of cutting parameters on different fabrics used in the search were investigated to determine the optimum parameters to apply it. Therefore, the impacts of these parameters selected on bending properties and color change on these fabrics were investigated. The fabrics have been tested on FAST-2 bending meter, before and after applied cutting design by using Co2 laser. In general, 100% cotton fabrics acquire elasticity after laser cutting through decreased bending rigidity. The blend ratio of synthetic fibers controls the degree of bending of fabrics after exposure to laser rays.

Keywords:
Co2 laser; cutting parameters; textiles; bending property; bending coefficient; sustainability

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1. Introduction:
Laser technology achieves the concept of sustainability therefore it is considered one of the cleanest industrial methods in the field of textiles [1]. After they were introduced in the 19th century, the fashion designers are widely adopting laser cutting in garment manufacturing [2]. Laser has established a new innovative solution, which successful prevents some of the weaknesses in the conventional technologies.
Laser cutting technology has been widely used in the clothing industry to cut patterns and designs for its accuracy, speed, flexibility, and simplicity of operation compared to other traditional cutting processes [3]. In synthetic fabrics, laser cutting produces well-finished edges as the laser melts and fuses the edge, which avoids the problem of fraying produced by conventional knife cutters. The unique nature of the garment manufacturing industry needs laser applications, which combines performance with reduced cost by eliminating the handling systems used in non-laser workstations [3]. Laser cutting is cheaper compared with the traditional cutting methods. Furthermore, as the laser cutting doesn't have mechanical action, high precision of the cut components at high cutting speed are feasible [3]. It has been established that one of the most crucial performance characteristics of clothing fabrics is fabric hand. It is defined as "perceived overall fabric aesthetic quality" [4]. Touch is the primary means of determining the quality of textile materials, and it directly affects how appealing a product is. textile hand impacts not just how customers view the items but also how they are developed from the point of design to the point of manufacturing and merchandising to the end user [5]. Fabric hand obtained by subjective assessment is a traditional procedure in which trained handle experts describe the fabric quality. On the other hand, defines fabric hand as the human tactile sensory response to fabric. This response involves not only physical variables but also physiological, perceptional, and social factors, all of which have a significant impact on the precision and repeated nature of the outcome. Objective assessment techniques, such as the Kawabata Evaluation System for Fabric (KES-F) and Fabric Assurance by Simple Testing (FAST) have been created since subjective evaluation is easily impacted by a variety of circumstances. These devices measure the low-stress mechanical characteristics of the fabric hand, including as bending, shear, tensile, and surface characteristics [5].
In this research, FAST-2 (bending meter) was applied to measure bending length (stiffness) of research fabrics. Fabric stiffness is used as the most common parameters used to gauge the drape rigidity [6]. Stiffness is expressed as the fabric's

resistance to bending or flexing [7]. The length that a fabric bends under its own weight is a measurement of the relationship between the fabric's stiffness and weight [8]. The fabric stiffness is closely related to the fabric structure, the weight of the fabric, fibers materials and yarn count [6]. An increase in the length of the bend means an increase in stiffness ratio [8]. There are differences in the angle of bending in the direction of the warp and weft, as the degree of bending of the warp threads is greater than the weft threads because the warp threads are finishing to resist mechanical processes and the force of friction during the weaving process. Fabric finishing influences shear and bending stiffness [10]. The bending coefficient of fabrics is affected by the properties of fibers and threads as well as the fabric structure, in addition to the finishing processing of the fabric [10, 11].

In this study, Co2 laser is used to cut the fabrics into the desired pattern shapes. A very fine laser is focused on to the fabric surface, which increases the temperature substantially and cutting takes place due to vaporization. (100% cotton, 99% cotton/ 1% lycra, 98% cotton/ 2% lycra, 74% Cotton/ 25% Polyester/ 1% Lycra and 78% cotton/ 21% Polyester/ 1% Lycra) fabrics have been investigated the optimum condition of laser variables (power and speed) which suitable to applied with these fabrics. Then study the fabrics bending properties, as the common property that relate to fabric esthetic side, as well as color change well be investigated.

2. Material and Methods:

The experimental work describes the use of Co2 laser as a cutting technique applied on cotton and cotton blended fabrics which obtained commercially to study the effects of laser cutting on the bending properties of these fabrics.

2.1. Materials and equipment:

2.1.1. Fabrics:

Six woven Fabrics selected with different variables used in this research, were obtained from Al-Robaiah Textile Factory, Gesr Al-Suez, Cairo. Fabrics specification used in cutting technique described in table (1)

Table (1) Fabric specifications used in cutting technique

		fabric composition	Fabric weight (g/m2)	Weave structure	Warp Density (end/cm)	Weft Density (pick/cm)	Yarn twist	color
Cotton 100%	1	100%Cotton	248	3/1 Twill	32	23	Z twist	Ocean blue/75
	2	100%Cotton	397	3/1 Twill	30	20	Z twist	blue
Cotton blended	3	99%cotton, 1%EA	336	3/1 Twill	33	22	Z twist	blue
	4	98%cotton, 2%EA	235	3/1 Twill	43	26	Z twist	blue
	5	74%Cotton,25 %PES,1% EA	343	3/1 Twill	39	26	Z twist	blue
	6	78%Cotton,21 %PES,1% EA	334	3/1 Twill	34	25	Z twist	blue

2.1.2. Laser machine specification:

The laser machine used in experimental work was CO2 Laser machine which is described in the table (2). The laser operations were carried out at the CNC Al-Obour Center, Cairo Governorate.

Table (2) CO2 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

2.1.3. FAST-2 instrument:

The bending test was carried out on FAST-2 (Bending Meter) which measures the bending length and hardness of the fabrics after laser cut, by using the cantilever bending principle described in British Standard Method (BS: 3356(1961)). The test was conducted in the physical testing lab of Golden Tex. Factory, 10th of Ramadan.

2. 2. Methodology:

2.2.1. Laser process

2.2.1.1. Preparation design

Adobe Illustrator software was used to create a suitable design using the vector method for the ability of a laser rays to implement various techniques. The design is transferred to the laser machine's program (RuiDa ACs work) to adjust the technology variables according to the techniques and material used in Fig. 1.

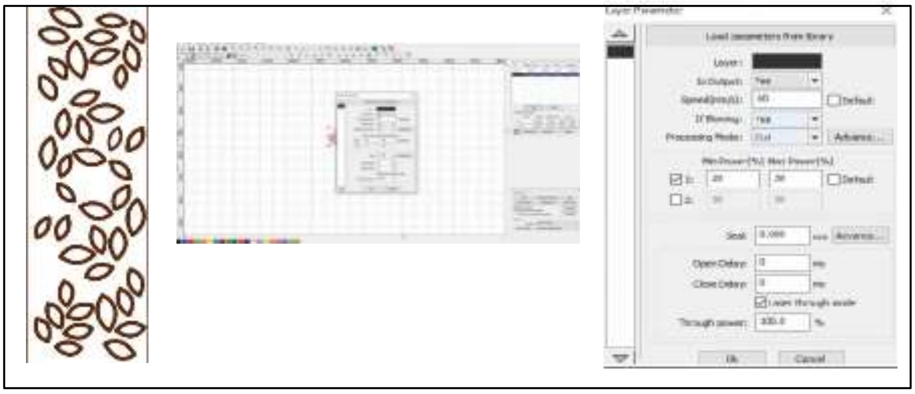


Fig. (1) The Design created by Adobe Illustrator software to make cutting laser technique in the study

2.2.1.2. Laser cutting technique parameters:

The laser cut parameters includes power and speed. These parameters applied with a constant height of the laser head above the surface of the material at 0.6mm.

The process was carried out by stabilizing the power and changing the speed until reaching the best variable on the material used then evaluating it visually. The laser variables were determined on these fabrics after initial experiments to determine the best parameter on the used fabrics. Table (3) shows the power and speed variables applied to these materials.

Table (3) Laser cutting parameters

Parameter*	values			
Power (W)	40	50	70	90
Speed (mm\s)	50	100	120	150

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

2.2.2. Preparation of fabric samples to laser cutting technique:

According to the fiber heat sensitivity behavior, the research fabrics whether cotton or blended cotton is undergoing as thermoset fabrics due to their fiber nature and the percent of blended with polyester. The research samples had prepared according to FAST-2 instrument dimension. Samples were cut in directions, warp and weft, measuring 500 mm in width and 1300 mm in length, according to FAST system template.

2.2.3. Laboratory methods of inspecting fabrics

2.2.3.1. Weight:

A circular piece with 10cm diameter was measured at electronic balance for calculating the weight of the fabrics in grams per square meter at a laboratory of Golden Tex. Factory, 10th of Ramadan city.

2.2.3.2. Bending test:

In this research, FAST-2 was used to measure the percentage of fabrics bending length and hardness after laser cut. FAST-2 (bending meter) measures the bending length of the fabric using the cantilever bending principle described in British Standard Method (BS: 3356(1961)). It has a smooth upper surface and the fabric strip is positioned on this surface and the platen is placed firmly on top of the strip leaving the leading fabric edge free. The fabric is then moved with platen towards and over the edge of cavity where it is allowed to drape. The fabric bends under its own weight until its leading intercepts a plan at angle of 41.5 degrees from the horizontal. The length of the fabric pushed over the edge till it bends to 41.5◦is called the bending length which in conjunction with fabric weight gives bending rigidity. Figure 2 had shown the principle of FAST-2.

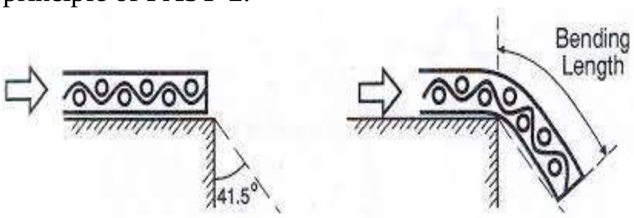


Fig. (2) The principle of FAST-2

2.2.4. Gray scale color change:

AATCC grey scale for color change test method used to determine the color change and yellowing rate for fabrics search after laser cutting to investigation quality optimum parameters for fabrics. 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 Standard Gray Scale panel with rating from (1-5) under its illumination D65.

3. Results and discussion:

3.1. Effect of laser parameters on fabrics cutting properties

Laser beam parameters (power and speed) described in table (3), were applied to the research fabrics which described in table (1). Visual examinations of cut fabrics were applied by grayscale to analyze the effect of laser different parameters. Also, bending properties and investigation of cutting edges quality were done.

3.1.1. The effect of laser speed and power parameters on cutting 100%cotton fabric (samples no.1& 2)

Research parameters started at constant power (40W) and gradually change the speed as follows

(50,100,120,150 mm\s) respectively. As shown in fig.3, samples (a-b-c-d) represents the effect of power (40W) parameter at different speed values, (e-f-g-h) represents the effect of power (50W) at different speed values, (i-j-k-l) represents the effect of power (70W) at different speed values, finally; (m-n-o-p) represents the effect of power (90W) parameter at different speed values.

Fabric No.1 (100%cotton -248g\m2)

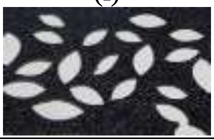
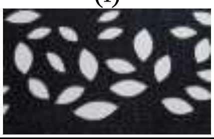
Speed / Power	50 mm\s	100 mm\s	120 mm\s	150 mm\s
40 W	(a) 	(b) 	(c) 	(d) 
50 W	(e) 	(f) 	(g) 	(h) 
70 W	(i) 	(j) 	(k) 	(l) 
90 W	(m) 	(n) 	(o) 	(p) 

Fig. 3, Effect of laser power parameters for cutting fabric no.1 100% cotton fabric

		Speeds mm/s			
		50	100	120	150
Power/w	40	a	b	c	d
	50	e	f	g	h
	70	i	j	k	l
	90	m	n	o	p

As revealed in fig. 3 at samples (a-b), the effect of the laser power parameter for cutting the fabric is completely with marks of burns on the cut edges at the power (40W) and the low speed (50 -100 mm/s). The cutting was not completed in some parts of the sample at high speeds (120-150 mm/s) at the same power, and therefore the power is not suitable for cutting process as samples (c-d). At constant power (50W) complete cutting to fabric at speed (50-100 mm\s) the cut edges are yellow with burn marks due to the high focus of energy that results from exposure to laser power for a longer period, as shown in samples (e-f). At speed (120-150 mm/s) the result of the cutting process is improved with increasing in the speed, and the thermal effect is reduced to be the best result of the cutting at (150 mm/s) speed, the sample is clear from any thermal effect as shown at sample (h). The high power at (70 &90W) and speed (50-100 mm/s) led to the burning edges parts of the fabric and its damage because of high focus of intensive energy of the laser power for a long time on the light-weight fabric. Therefore, the sample does not endure the high power as shown in (i, j, m & n). At the high speeds at the same power, the result was burning marks on the edges of the cut and some of the fabric parts as shown in (k, l, o & p). Low power and low-speed laser parameters lead to burn and removal of the dye from the cut edges, as shown in fig. 3. High power is the high thermal effect on the sample due to the oxidation of cotton fiber resulting from the power of the laser beam on the cellulosic fibers. ***Therefore, power (50W) and high speed (150 mm/s) are the optimum for the sample No.1***

Fabric No.2 (100%cotton-397gm2)

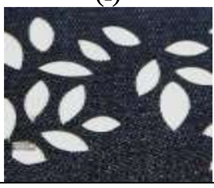
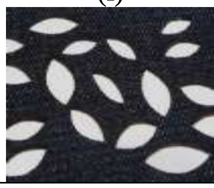
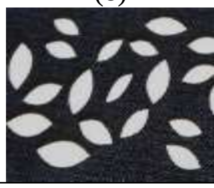
Speed / Power	50 mm\s	100 mm\s	120 mm\s	150 mm\s
40 W	(a) 	(b) 	(c) 	(d) 
50 W	(e) 	(f) 	(g) 	(h) 
70 W	(i) 	(j) 	(k) 	(l) 
90 W	(m) 	(n) 	(o) 	(p) 

Fig. 4, Effect of laser power parameters for cutting fabric no.2 100% cotton fabric

		Speeds mm/s			
		50	100	120	150
Power/w	40	a	b	c	d
	50	e	f	g	h
	70	i	j	k	l
	90	m	n	o	p

As shown in Fig. 4 at the constant power 40W and speed 50 mm/s, the sample was completely cut with cut edges yellow noticeably, sample (a). The effect of yellow is present with the incomplete cutting of the sample parts at speed (100-120-150mm/s), samples (b-c-d). The yellowing of the cutting edges can be a result of a long-time concentration of power for the cutting process, which led to carbonization and yellowing of the cotton fibers. The effect of cutting did not differ much at the constant power 50W with different speeds, so the speeds (50-100 mm/s) led to the yellowing the cut edges, as shown at samples (e-f) and to incomplete cutting in the parts of the sample as the speed increased, samples (g-h) and therefore the speed & power are not suitable for the material. The higher laser power value 70-90W with speeds about 50-100 mm/s increasing the thermal effect which causes yellowing of the cutting edges with burn is shown at samples (i, j, m & n). These effects were reduced at the higher speed (120-150 mm/s) at the power of (70W) compared with the same speed at power 90W. Therefore, they were chosen as the best variable on the sample of the fabric to be a speed of (150 mm/s) due to reducing the thermal effect of laser rays to the material for its high speed, see sample (i). As for power (90W), the sample is yellow with slight burn marks due to the strong impact of the laser power on it, see samples (o-p). As shown in Fig. 4, it can be concluded that the effect of laser power whether very low or very high on the material has a more thermal effect at different speeds. ***Therefore, the power (70W) and speed (150 mm/s) are the optimum for the sample No.2.***

3.1.2. The effect of laser speed and power parameters on cutting cotton blended fabric (samples 3, 4, 5 & 6)

Fabric No. (3) (99%Cotton/1%Lycra -336gm2)

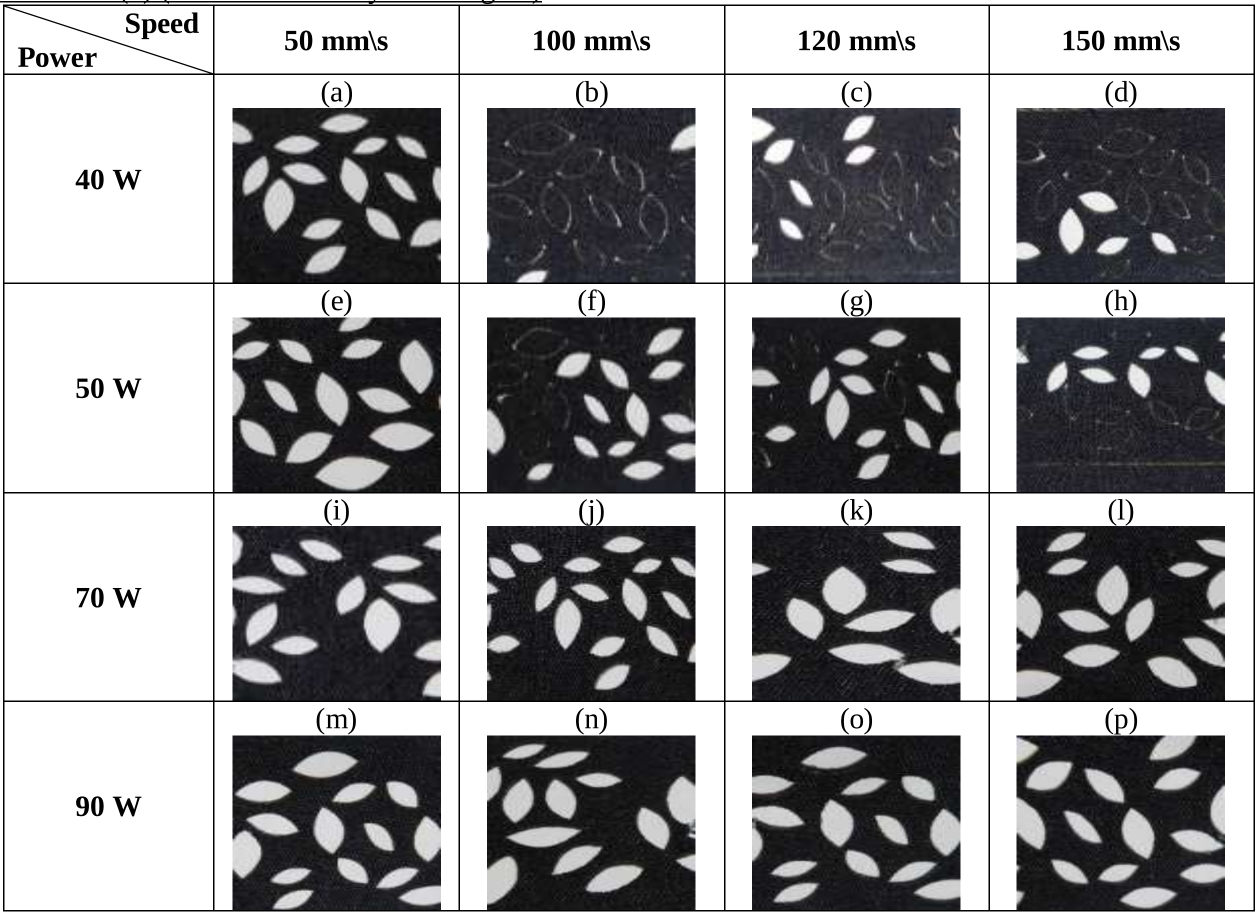


Fig. 5, Effect of laser power parameters for cutting fabric no.3 cotton blended fabric

		Speeds mm/s			
		50	100	120	150
Power/w	40	a	b	c	d
	50	e	f	g	h
	70	i	j	k	l
	90	m	n	o	p

As shown in fig. 5 at power 40-50W and speed (50mm/s), the sample is completely cut with yellowing of the edges as shown at samples (a & e). At the high speeds (120-150mm/s), for the same powers, the samples are not cut completely, as there are some parts of the sample that are not cut or partially cut. This is due to the power is low, and the speed is high, therefore the energy of laser rays focused on the fabric is less on the sample as shown at samples (b, c, d, f, g, and h).The fabric material (99%Cotton/1%Lycra) is affected thermally at power (70-90W) and low speeds (50-100 mm/s) by the yellowing and burn marks appearing on the edges of the cut as shown at samples (i, j, m, and n). This effect decreases as increases the speed. At the high speed and power (70W) the thermal effect is decrease and the cut edges are clean compared with the sample at power (90W), Therefore the speed (150 mm/s) is optimal as shown at sample (p). This sample is the closest to 100% cotton samples because the proportion of cotton fibers is up to 99%, so, no affected by 1% of acrylic fiber. As revealed in fig. 5, the thermal effect of laser ray’s parameters on a fabric material more intensive at parameters of high power and at parameters low speed due to exposing the fabric material to the power laser rays for a long period resulting to oxidation the cotton fibers and due to absorption of high thermal energy by the power of the laser beam. ***Therefore, power (70W) and speed (150 mm/s) are the optimum for the sample No. 3.***

Fabric No. (4) (98% Cotton/2% Lycra -235gm2)

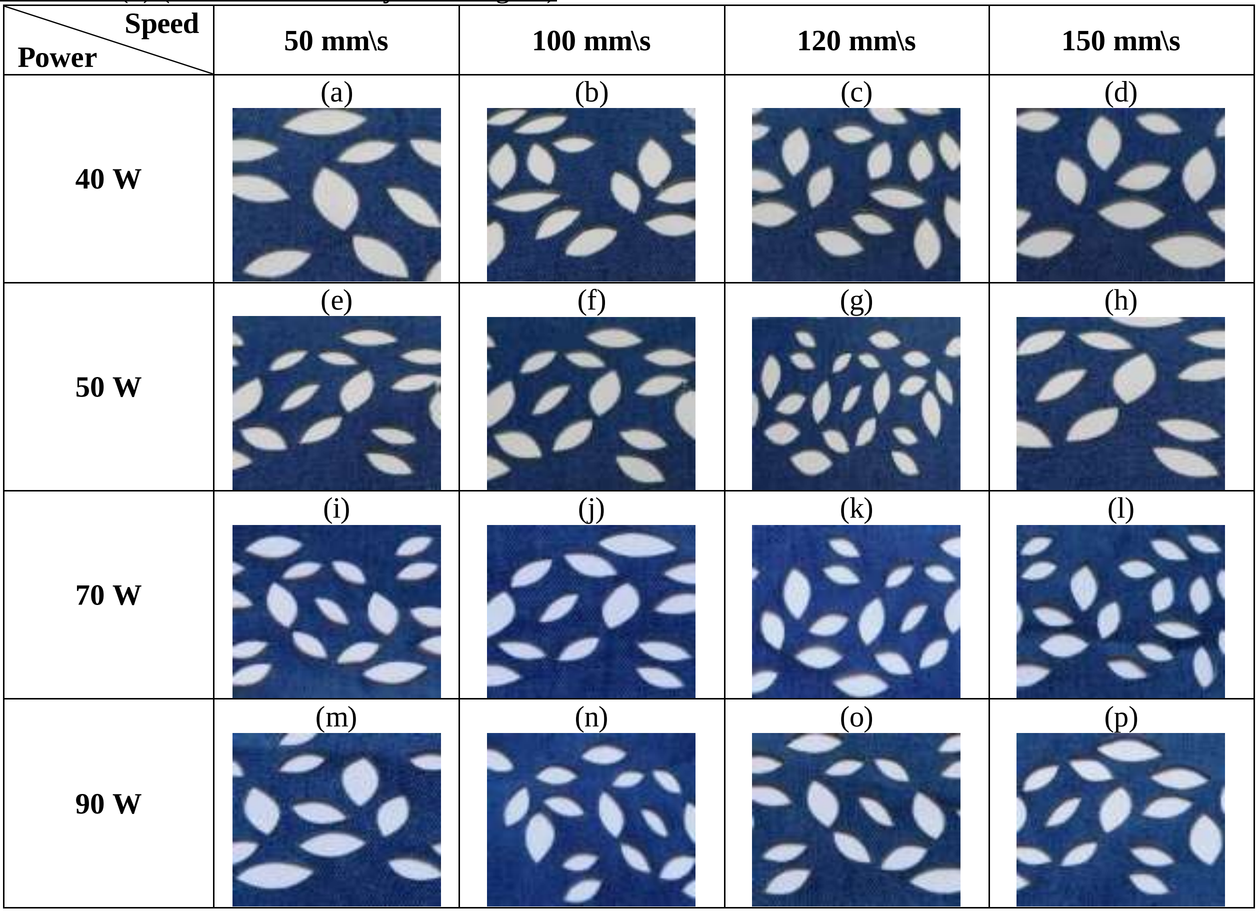


Fig. 6, Effect of laser power parameters for cutting fabric no.4 cotton blended fabric fabric

		Speeds mm/s			
		50	100	120	150
Power/w	40	a	b	c	d
	50	e	f	g	h
	70	i	j	k	l
	90	m	n	o	p

Figure 6 shows the burn marks and yellowing occur at the constant low powers (40-50W) with low speeds (50-100 mm/s), this is related to the duration of the fabric exposure to laser rays as shown at samples (a, b, e, and f). The thermal effect is decreased at power (40-50W) with high speed (120-150 mm/s), due to the short time of exposure to laser power as shown at samples (c, d, g, and h). Therefore, the power (50W) and speed (150 mm\s) are the optimum parameters on the material when compared with power (40W) at the same speed as shown at samples (d & h). The thermal effect of laser beam power is intensive at high power as (70-90W) at different speed parameters due to the appearance of different burn marks on parts of the material and the edges of the cut, and therefore the high power is not suitable for this sample of the fabric as shown in fig 6. Also, the sample was completely cut at different powers and speeds variables due to the light weight of the sample (235g/m2). Long fabric exposure to a laser power beam at low value and the intensive thermal effect of the laser power beam resulted in this will lead to burn marks and yellowing of the material due to the presence of a high percentage of cotton in the sample of the fabric, reaching (98%). The yellowing of cotton fibers due to the thermal oxidation by the laser beam causes a reduction in the hydroxyl groups and the formation of carbonyl groups then the cotton fibers start to degradation [12]. ***Therefore power (50W) and high speed (150mm/s) are the optimum parameters for this material.***

Fabric No. (5) (74% Cotton/ 25% Polyester/ 1% Lycra -343gm2)

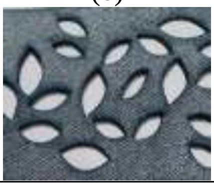
Speed / Power	50 mm\s	100 mm\s	120 mm\s	150 mm\s
40 W	(a) 	(b) 	(c) 	(d) 
50 W	(e) 	(f) 	(g) 	(h) 
70 W	(i) 	(j) 	(k) 	(l) 
90 W	(m) 	(n) 	(o) 	(p) 

Fig.7, Effect of laser power parameters for cutting fabric no.5 cotton blended fabric

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="4">Speeds mm/s</td></tr>
<tr><td>50</td><td>100</td><td>120</td><td>150</td></tr>
<tr><td rowspan="4">Power/w</td><td>40</td><td>a</td><td>b</td><td>c</td><td>d</td></tr>
<tr><td>50</td><td>e</td><td>f</td><td>g</td><td>h</td></tr>
<tr><td>70</td><td>i</td><td>j</td><td>k</td><td>l</td></tr>
<tr><td>90</td><td>m</td><td>n</td><td>o</td><td>p</td></tr>
</table>

In fig.7, the Laser power (40W) with low speed (50-100 mm/s) causing complete cut with burn and yellowing mark on cut edge at samples (a & b). The high-speed parameter (120-150 mm/s) with the same power led to incomplete cutting in some part of sample due to the energy of the laser beam was not enough to complete the cutting process completely on the material, as result of short time to exposing to laser power as shown at samples (c-d). At constant power (50W) and low speed (50-100 mm/s), the cut edges have dark and burn marks, but its effect are decrease with high speed (120- 150mm\s) as shown at sample (h). ***Therefore, the power (50W) and speed (150 mm/s) are the optimum of this fabric***. The high laser power as (70-90W) at the various laser speed values have an intensive thermal effect on the cut edges significantly, it led to the burning of the sample due to intensive thermal energy result from laser power ray focused on fabric surface, also it led to a change in the color of cut edges the material to dark hues as shown at samples (i, j, m, and n). This may be due to the effect of thermal cutting on the dyed fibers, which increases the darkening of the color as a result of the melting and re-hardening of the Polyester and Lycra fibers where, a study [13] indicated to the polyester fabric become more in darker in the color appearance when exposure to high laser parameters. Therefore, it is not suitable for the material. Due to the presence of polyester in the fabric structure up to 25%, which made most of the cut edges at different power and speed parameters have a coarse feel due to the melting of the polyester fibers and re-hardening them again, thus forming the edges of the fibers with a solid spherical black end. ***As shown in fig.7, at sample (h), power (50W) and speed (150mm\s) are clear from any thermal effect resulting from thermal cut by laser beam.***

Fabric No. (6)(78% Cotton/21%PES/1% Lycra- 334gm2)

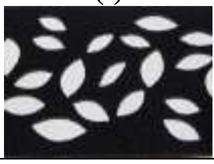
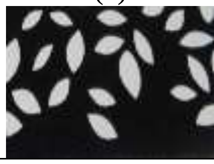
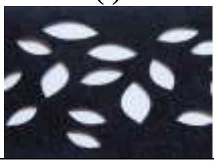
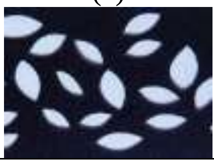
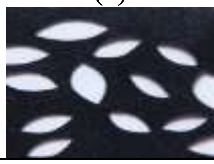
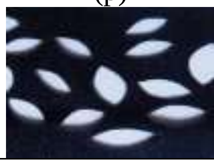
Speed / Power	50 mm\s	100 mm\s	120 mm\s	150 mm\s
40 W	(a) 	(b) 	(c) 	(d) 
50 W	(e) 	(f) 	(g) 	(h) 
70 W	(i) 	(j) 	(k) 	(l) 
90 W	(m) 	(n) 	(o) 	(p) 

Fig. 8, Effect of laser power parameters for cutting fabric no.6 cotton blended fabric fabric

		Speeds mm/s			
		50	100	120	150
Power/w	40	a	b	c	d
	50	e	f	g	h
	70	i	j	k	l
	90	m	n	o	p

As shown in fig. 8, completely cut edges of the samples at power (40-50W) accompanied with low speed (50-100 mm/s) are thermally affected the fabric burn mark on cut edges at samples (a, b, e, and f). At constant power (40W) and high speeds (120-150 mm/s), partially fabric cut due to occur the insufficient time for the fabric to be exposed to the thermal energy of the laser beam as shown in samples (c & d). At constant power (50W) and high speed (120-150 mm/s) as shown at samples (g & h), the effect was decreased to disappear at speed (150 mm/ s), therefore, it is the optimal variable at (h). The high power (70-90W) resulted in burn marks appearing on the cutting edges and some parts of the fabric at different speed parameters due to intensive thermal energy emitted from the laser beam, therefore this power is not suitable for the material as shown at samples (i, j, m, n, k, l, o & p).As revealed in fig. 8, low power (50W) has less adverse effect on fabric appearance compared with other laser power parameters at same speed (150 mm/s), this is may be due to the presence of polyester and Lycra fiber in the fabric structure that is required to cut at low power and high speed. Therefore, power (50W) and speed (150mm/s) are suitable for sample fabric and are considered as the optimum laser parameters for cotton\ polyester\ Lycra fabric cutting effect.

Table (4) the optimum laser cutting parameters for study fabrics

Study parameters / Sample No.	Power W	Speed mm/s	Weight/gm
Cotton fabrics 100%			
1 100%Cotton	50W	150 mm/s	248g/m2
2 100%Cotton	70W	150mm/s	397g/m2
Cotton blended fabric			
3 (99% Cotton, 1% Lycra)	70W	150 mm/s	336g/m2
4 (98%Cotton, 2% Lycra)	50W	150 mm/s	235 g/m2
5 (74%Cotton,25%polyester,1%Lycra)	50W	150 mm/s	343 g/m2
6 (78%Cotton,21%polyester,1%Lycra)	50W	150 mm/s	334 g/m2

3.2. Effect of laser cutting parameters on color change by gray scale for different research fabrics

The grayscale test was applied to evaluation the fabric appearance and quality of cut edges at optimum power parameter and different speeds to determine optimum parameters. Laser cutting with the speed parameter of (150mm\s) achieves the best result on the research samples, although vary the laser optimum power according to each material. Gray Scale consists of panel with ratings from (1-5) which (5) present cutting edges without thermal effect and (1) represent deforming and burning cut edges.

Table (5) Color change for cotton, cotton blended fabrics at optimum laser power and different speed laser parameters

Fabric no.	**Cotton 100%**	**Cotton 100%**	**99%Cotton, 1%Lycra**	**98%Cotto, 2%Lycra)**	**74% Cotton, 21% PES,1% EA**	**78%Cotton,25 %PES,1% EA**
	no.1	no.2	No.3	No.4	No.5	No.6
Optimum power/W / Speeds mm/s	50 W	70W	70W	50W	50W	50W
50mm\s	2/3	2	3	2/3	1/2	2/3
100mm\s	3	3	3/4	3	2	3
120mm\s	3/4	3/4	4	3/4	3	3/4
150mm\s	4/5	4	4/5	4/5	3/4	4

*1 means high change, while 5 means no change

Table 5 shows that the laser speed parameter of (150 mm/s) achieves as nearly on color change the best result on the 100% cotton research fabrics obtains (4\5&4). The research fabric No.1 (100% cotton, 248g/m2) achieves the best results at laser power 50W which obtains (4\5). The lowest speeds increase the thermal effect at the cut edges. The thermal effects was appeared with yellowing and white halo around the cut edges due to start oxidation the cotton fiber and decompose of the warp yarn dye. A study [14] indicated that increasing the laser energy enhances the effect of thermal oxidation and contributes to the yellowing of the surface of the fibers. For fabric No.2 (100% cotton, 397g/m2), achieves the best results at laser power 70W which obtains (4\5). The color change at the low speed has a burning and dark burn occur at cut edges due to thermal carbonize for cotton fibers resulting from the intensity of the effect of the energy of the laser beam for a longer time on the cotton fibers [15]. Therefore, high speed (150mm/s) is the optimum parameter on 100% cotton fabrics.

On the other hand, the presence of polyester and Lycra fibers in the research blended fabrics produces a color change that varies according to the fiber blending ratio. As shown in table 5, color change for fabric No.3 & 4 are similar and close to the color change of cotton fabrics due to the increase in the percentage of cotton and the absence of polyester fibers, also that the percentage of Lycra is also simple, as yellowness appears to the edges of the cut with the appearance of white hue around it, as a result of the start of oxidation of the cotton fibers with partial removal of dyeing of the warp threads. The effect appears more clearly on sample No.4 as a result of the lighter-colored warp yarn compared to the darker warp yarn of sample3. Both samples obtain (4\5) due to disappears the thermal effect at the high speed.

For fabrics No. 5& 6, the color change was the darkening of the color cutting edges with the appearance of burnt edges at the lowest speed. This effect is due to the melting of the polyester fibers, which leads to darker cut edges after hardening. The effect appears at the fabric no. 5 by the presence of a dark hue on the edges of the cut clearly because of fused thermoplastic fiber that makes the cut edges dark this effect was decreased at high speed was obtained (3/4). A study [16] indicated the color change is increased with an increase in the laser rays parameters, where the polyester becomes dark when exposed to high laser rays parameters .For the fabric No.6, the cutting edges of dark color as a result of the fusion of the thermoplastic threads as a result of thermal cut were obtained (4) at high speed (150mm\s) [17]. ***Therefore, the optimum parameters at a high speed of (150 mm/s) on the cotton/polyester/Lycra fabrics.***

Investigation of cutting technology quality for the best and least research samples:

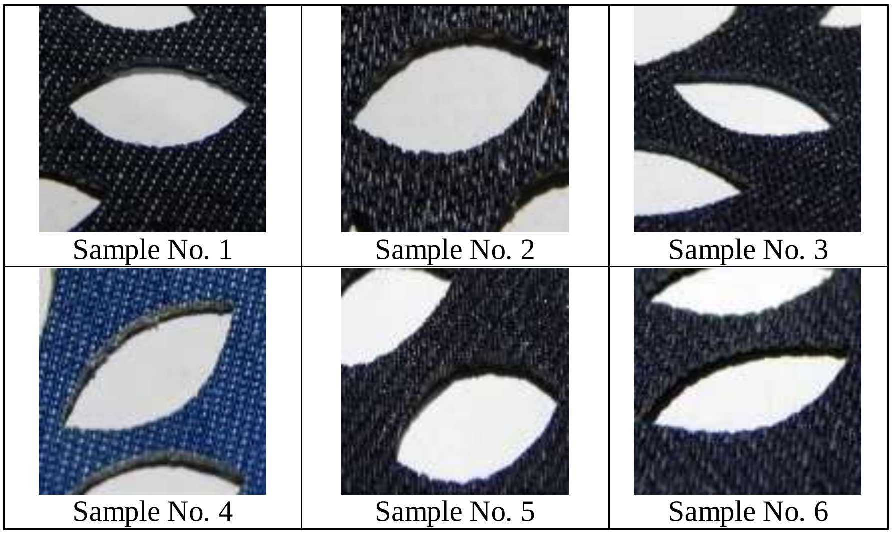


Fig. 9, Optimum laser cut parameters on the research fabrics study

The cut edges of the study fabrics appear completely free and clean from any thermal effect resulting from the cut by laser beams as shown in fig.9 to cut each fabric at the optimum laser variable for it. At fabric no.2(cotton 100%, 397g/m2) the cutting edge of the fabric is free from the thermal effect of laser cutting to show the cutting quality of the cotton at the power of (70W) and a speed of (150 mm/s) optimal parameters. On the other hand, the fabric no.1 (cotton 100%, 248g/m2) marks of yellowing and oxidation of the cotton fibers appeared, in addition to the removal of parts of the dye fibers of the warp threads as a result of laser rays at 70W. So, the quality of the cut edges at the optimum variable for power (50W) and speed (150 mm/s) is shown at fabric no.1.

In a similar effect for fabric no.1 (100% cotton fabrics, 248g/m2) when exposed to unsuitable variables for laser rays, the fabric no. 4 (98% Cotton, 2% EA, 235 g/m2) has yellowed and burned fiber at power (70W), speed (150 mm/s), this is due to low weight of these samples so, the power (50W) at the same speed, was prefer to fabrics no.1 and no.4 as shown in fig. 9. We must note that the percentage of cotton fibers in blended fabric No. 4 reaches 98%, at the same time; the fabric weight is very close to fabric no.1.

Relationship between laser power and speed parameters in cutting process

The relationship between laser power and speed is evident in the following points:

- When the power decreases and the speed increases, there is no cutting, technique occurred.
- High power and low speed lead to burn and deformation the cut edges.
- High power with high speed can lead to partial cutting sometimes.
- Very high-power values at different speeds leads to burn and damage to the cut fabric edges. This is also indicated by a study [18].

The relationship will also be proven through the study [19] of laser cutting for different types of textiles to measure the kerfs' width, overcut and sideline through laser cutting variables. Increasing the melting or evaporation of the speed to low one increases the kerfs' width, and it happens because of exposing the fabric for a longer time to the laser heat, and thus increasing the amount of melting or evaporation to be the best cutting results for low power and high speed for all types of study fabrics.

Effect of fiber composition and thermal decomposition for it in determine laser parameter for cutting quality

The fiber composition and its thermal properties are particularly important in the laser parameters for the quality of the cutting process. The behavior of the fibers when exposed to heat is divided into melt or decomposition, as this depends on whether the fibers are natural or synthetic. The polymer that re-solidified after undergoing melting or softening upon heating is called thermoplastic polymers. On the other hand, thermoset polymers are infusible and cannot be re-molten or reformed [20]. Depending on that, the optimal variable is determined by the effect of laser variables on the nature of these fibers.

100% cotton

It can be noted from the experimental process for laser cutting in 100% cotton fabrics that, the fabric no.2 is cut at power (70W) and speed (150 mm/s). While fabric no.1 is cut at power (50W) and speed (150 mm/s) that may be due to decrease the weight of the sample when compared it with fabric no.2. The high temperature as a result of the high power or exposure the fibers to a long time to laser beams leads to damage the cotton fibers. The cotton fibers begin to turn yellow as a result hydro celluloses are 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 color that gradually darkens to a darker brown [21]. Therefore, the power of (90W) was the most harmful to the fibers due to the intensity of the high thermal energy emitted from the laser beams, which languishes in the carbonization and burning of the cut edges of the 100 % cotton fabric, when indicated by a study [19] in a study of cutting different types of fabrics, the high energy of the laser rays increases the amount of heat, which means an increase in the amount of molten fabric and evaporated away.

<u>Cotton\ polyester\ Lycra</u>

Fabric No.3 was cutting at laser power value (70 W) and speed (150 mm/s). For fabric structure may be the existing cotton fiber in percentage reach (99%), and Lycra (1%), which make it close to the optimum laser parameter cut for 100% cotton fabric; especially at fabric no.2, which closed to in its weight. Most of the fabrics that include polyester and Lycra fiber with different percentage are cutting at the same power (50 W) and speed (150 mm/s), that include fabrics no.5 & 6. These fabrics cut of the optimum parameters due to presence the synthetic fibers. A study [22] proved that the best results for cutting fabric were 25% cotton and 75% polyester, and the weft was 100% polyester, as they indicated that increasing the percentage of polyester when blending with cotton when cutting with the study variables for laser improves the quality of the produced fabrics. On the other hand, the percentage of synthetic fibers in fabrics affects the quality of cutting edges. Fusing and re-hardening of synthetic fibers when thermal cutting with laser rays makes the edges of the cut fabric rougher. This is a result of the formation of hard spherical ends, which makes the edges of the cut look inaccurate. This effect increases with the increase in the percentage of synthetic fibers, and this is what was observed in fabrics No.5 & 6, that the percentage of polyester fibers reached to 25% at fabric no.5. The rate of the roughness decreased, the higher the energy as a result of the increase in the power of the laser ray, which means a greater melting for the fibers, and thus the smoothness of the cut edges, so that the power (50W) and speed (150 mm/s) are the best suitable laser parameters. This is what was found by (22) research, where there is an inverse relationship between the degree of smoothness of the cut edges and the cutting using the laser due to the swelling and fusion of the cut edges. Especially at low power compared with samples without laser treatment. This was also confirmed by a study [23] to determine the best variable for the Co2 laser cutting and marking process, from speed and power, for a fabric that has a composition of (65%) cotton and (35%) polyester, to be the best result of cutting at a constant power of (10W) and different speeds due to this cut is becoming a full cut and is the most economical use of this type of laser.

3.3. Effect of laser cutting parameters on the bending coefficient on different research fabrics

The effect of laser cutting parameters on the bending coefficient of fabrics 100% cotton

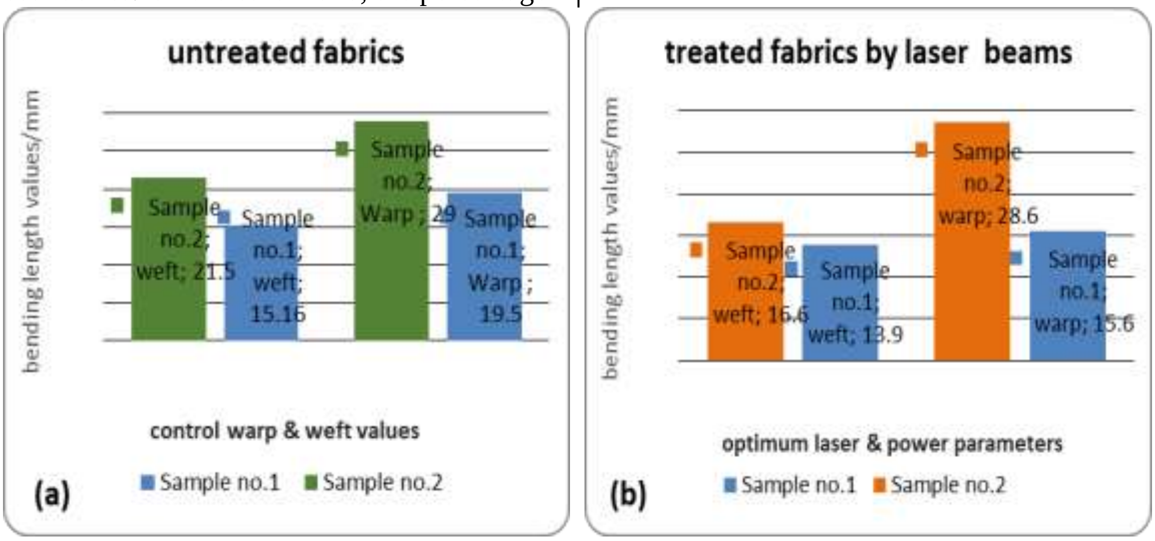


Fig.10 Binding coefficient property (a) Untreated 100%cotton samples (b) Optimum treated fabrics at power (50W) and speed (150mm\s) for Fabric no.1(100%cotton- twill 3/1- 248g/m2) & Power (70W) and speed (150 mm/s) for Fabric no.2 (100% cotton- twill3/1-397g/m_2)

According to the above figure that represents the relationship between laser cutting variables and their effect on the bending coefficient on the fabrics 100% cotton. Laser cutting parameters were chosen as the optimum variable on the fabric sample, which varies according to the specifications of the sample itself. The bending percentage of the cotton fabrics no.1&2 were affected after applying the variables of laser compared with the original samples. As shown in fig.10, the bending length of the laser-cut fabrics in the two directions of warp and weft in general was reduced in different proportions according to the fabric used which means that the stiffness of the fabric decreased compared with the control sample fig.10 (a). For fabric No.1, the percentage of decrease in warp direction by about (-20%) and in weft about (-8.3%), while for fabric No.2 about (-1.4%) in warp and about (-22.8%) in weft. as shown in table 6.

Table 6 Effect of laser optimum parameters on the stiffness of research fabrics

	Bending length(mm) of Cotton fabrics 100%			
	control		**treated**	
	warp	**weft**	**warp**	**weft**
Fabric no.1	19.5	15.16	15.6 (-20%)	13.9 (-8.3%)
Fabric no.2	29	21.5	28.6 (-1.4%)	16.6 (-22.8%)
	Bending length(mm) of Cotton blended polyester/ Lycra			
Fabric no.3	28.36	20.25	23.08(-18.6)	17.9(-11.6)
Fabric no.4	22.25	15.5	20.75(-6.7)	14.5(-6.5)
Fabric no.5	26.08	19.5	25.5(-2.22)	18(-7.7)
Fabric no.6	27.08	23.5	27.8(-6.6)	19.25(-18.1)

The decrease in the degree of bending length in the cotton fabrics after laser cutting indicates a decrease in the weight of samples because of removing a part of the fabric resulting of the shape of the executed design. Also, it should be noted although all samples have the same weave structure (Twill 1/3), cotton fibers are relatively inelastic and bear high temperatures, therefore the cotton material was affected by the laser beams used, as laser cutting at these variables change the elastic properties of the cotton fiber material. ***Therefore, the 100% cotton fabrics acquire elasticity after applying laser cutting parameters compared with the fabrics before the treatment that is mean decrease fabric stiffness for cotton fabric.***

The effect of laser cutting parameters on the bending coefficient on cotton \Polyester\Lycra blend fabrics

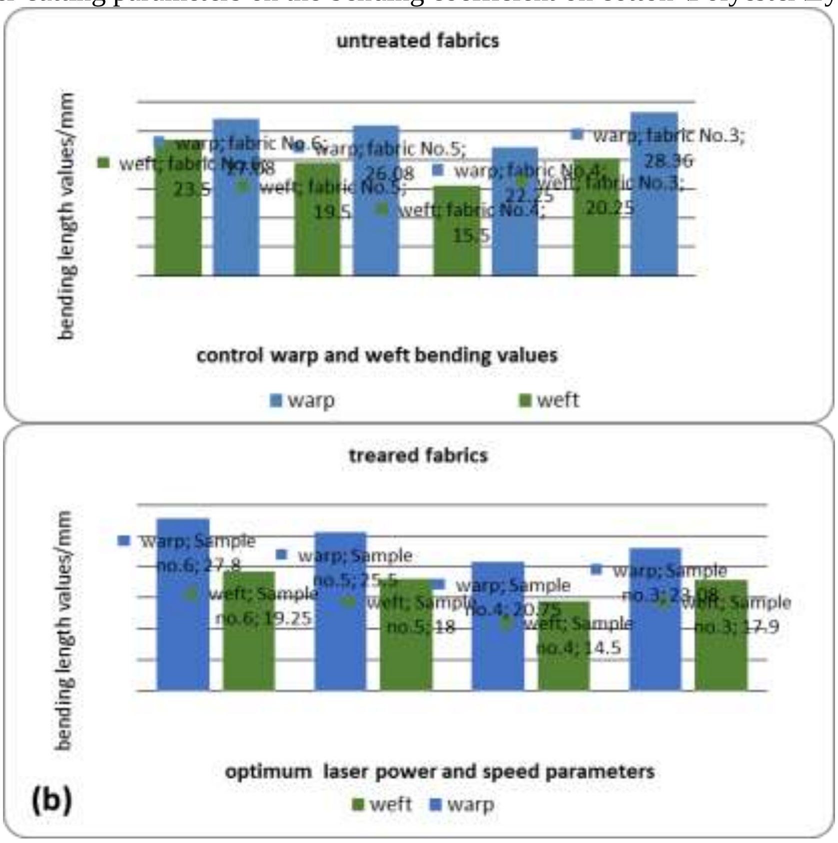


Fig.11, Binding coefficient property (a) untreated fabrics for cotton/polyester/Lycra blend fabrics (b) Optimum treated fabrics at power (70W) and speed (150mm\s) for fabric no.3 (99%Cotton/1%Lycra-336gm2). Power (50W) and speed (150mm\s) for fabric no.4 (98%Cotton-2%Lycra-235gm2), fabric no.5 (74%Cotton/25%Polyester/1%Lycra-343gm2), and fabric no.6 (78%cotton-21%polyester/1%Lycra-334gm2).

The cotton blended fabrics no.3, 4, 5 & 6 were affected by different percentages of cotton, polyester and Lycra fibers, with similar weave structure (Twill 3/1), and different weights. The laser parameters were selected according to it being the best parameter suitable for the material used. As shown in figure 11 (a) the degree of bending of the samples variated relative to the warp and weft directions. The bending length varies according to the blending ratio and the weight. Bending length for fabrics no. 3&4 have decreased in bending length for warp and weft direction compared with bending length for control as shown in fig.11 (a &b). The fibers composition of fabrics which have large percentage of cotton fiber which make it closer to 100% cotton fabric thus, the reason for the decrease in the stiffness of the fabrics is as a result of the cotton fibers gaining more elasticity after cutting them with laser rays, which led to a decrease in the bending length and an increase in its drape ability. Lycra fibers did not affect the bending length due to its small percentage in the composition of the fabric no.3 which decreased up to (-18.6%) in warp direction and about (-11.6%) in weft after laser cut compared with the bending length for untreated sample. As for fabric no.4, the percentage of bending length decreased in the warp direction about (-6.7%) and (-6.5%) in weft direction compared with bending length for untreated sample as shown in table 6.

Increases in bending length of the fabric no.3 as shown in fig. 11 (a &b) as result of increasing its weight compared to fabric no.4, despite the slight increase in the percentage of Lycra fibers in sample No. 4. which is supposed make fabric stiffer due to fused and re-solid Lycra fiber when cut by laser ray. On the other hand, Stiffness of fabric that has large percent of polyester fibers is relatively low compared with the control sample as shown at fabric no. 5 in fig.11 (a-b). The decrease percentage in bending length for fabric no.5 are about (-2.22%) in warp and about (-7.7%) in weft is less percentage after laser cut due to present the polyester and Lycra fibers that make the fabric more resistance to bending after laser cut parameter; while the fabric no.6, the percentage decrease of bending length after laser cut about (-6.6%) in warp and (-18.1%) in weft direction, the fabric is decrease in stiffness after laser cut parameter. The decrease in bending percentage of the fabric due to removing part of fabric resulting from laser cut design employment that makes the fabric light in the weight and more drape. On the other hand, the decrease is relatively small decrease bending percentage for samples (5&6) due to the increase in the percentage of polyester in the fabric sample. Fabric stiffness is affected by the friction of fibers and threads with each other [7]. When the cutting happens by laser rays for materials blend with polyester, the polyester fibers melt and cover the cotton fibers adjacent to them, and thus limit the movement of the threads and increase the percentage of stiffness. Restricting the freedom movement of the fibers and threads increases the stiffness of the fabric due to the increased inter-fiber friction and adhesion [10]. This is what has been seen in fig. 11 (a& b), so that the bending length in both the warp and weft directions is slightly lower compared with the bending length of the control sample. ***Finally, laser cutting can reduce the hardness of fabrics, depending on the composition and weight of the fabrics.***

4. Conclusion:

In this study, the effect of laser parameters (power and speed) on cotton and blended fabrics were studied, and then these effects on the bending properties were revealed. The results can be summarized as follows:

- When the power decreases and the speed increases, there is no cutting technique occurred.
- High power and low speed lead to burn and deformation the cut edges.
- High power with high speed can lead to partial cutting sometimes.
- A very high-power value at different speeds leads to burn and damage to the cut fabric edges.
- The optimum parameters for 100% Cotton fabrics at power 50 and 70 W and speed 150 mm/s, which are determined depending on the weight of the fabric used,
- Depending on the ratio of blending the thermoplastic fibers in fabric construction, the power 50 W and speed 150 mm/s were the optimum laser ray parameters for Cotton/Polyester /Lycra fabrics.
- Optimum parameters of objective evaluation by grayscale for 100% cotton and Cotton/Polyester/Lycra fabrics achieve good evaluation compared with other laser parameters due to disappearing yellowing and carbonization due to thermal oxidation.
- In general, 100% cotton fabrics acquire elasticity after laser cutting through decreased bending rigidity.
- The blend ratio of synthetic fibers controls the degree of bending of fabrics after exposure to laser rays. Fabrics with a high blending ratio of synthetic fibers maintain a limited decrease in bending length as a result of the solidification

of the fibers after melting on the edges of the sample cut.

- The percentage of bending is due to the removal of part of the fabric resulting from the design of implemented by laser beams.
- The solidification of synthetic fibers after melting reduces the movement and friction of the yarns with each other, which means an increase in the stiffness of the synthetic fabrics when exposed to laser radiation.
- Laser cutting can reduce the bending length and stiffness of fabrics, depending on the composition, weight of the fabrics, and design used.
- The laser cutting technique is suitable for clothing pieces in general, because of the advantages achieved by this technology for the quality of cutting on different materials, in addition to increasing the visual effect of the hollow-out resulting from the cutting process, which is commensurate with modern fashion.
- Finally, laser technologies have succeeded in creating products that are characterized by innovation and modernity in terms of design quality, aesthetic and functional properties, and compatibility with contemporary fashion and sustainability.

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