Abstract: A method is disclosed for selectively modifying an elastic modulus of a process region of a textile substrate. A plurality of sub-regions within a process region of the textile substrate are exposed to a power beam so as to cause melting and coalescence of the textile fibres within each sub-region. This causes at least one elastic modulus of the textile within the process region to be modified with respect to the said at least one elastic modulus of the process region prior to the exposure of the sub-regions to the power beam. The modification of the at least one elastic modulus is dependent upon the combined effect of the exposure of the plurality of sub-regions to the power beam. A textile modification system for performing the method is also disclosed.
TEXTILE MODIFICATION METHOD

Field of the Invention
The present invention relates to the modification of textile materials using a power beam, such textiles including fabrics.

Background to the Invention
The fabric and textile industry has a desire to modify the properties of its products to add unique functionalities. This is of especial interest within the sportswear industry where clothing performance is becoming an increasing consideration alongside aesthetics. Changes to the mechanical properties, such as elastic modulus, of the fabric used in clothing can be used to add functionality in, for example, sports apparel. This has been shown to assist performance during exercise and accelerate recovery. Garments that compress the body can assist muscular and circulatory system operation and provide shaping, such as for streamlining in swimwear. Similar benefits have also been shown in a wide range of other applications, including in garments that apply compression for medical applications and for military applications.

Although small percentages of elastic fibres (e.g. elastane, a polyester-polyurethane copolymer, also known by brand names such as Spandex® and Lycra®) have been integrated within the manufacture of sportswear fabrics since the 1970s to improve freedom of movement and comfort, it was not until the mid-1990s that the advantages of compression on athletic performance and recovery were realized. From the turn of the century numerous sportswear brands have been integrating compression fabrics within their collections. Speedo®s FSIII swimsuit, widely used at the 2012 Olympic Games, was made from a warp knitted fabric that had variable elastane density across its surface, to target specific areas of the body for compression. This streamlining effect was shown to provide significant advantage to athletic performance by improving race times.

Elastic modulus increases with elastane content, assuming that the surrounding fabric is constructed using a knit or weave that is easily extensible. Fabrics with high percentages (5-25%) of elastane are typically used for compression
apparel. Gradient compression socks have been used for over 50 years for the treatment of chronic venous insufficiency. Medical compression hosiery is designed to provide extra support to assist in the flow of blood back to the heart that prevents blood pooling in the lower ankle. Compression apparel is also used to increase the rate of blood flow around the body which has been shown to have an enhancing effect on athletic performance. As well as improving performance during exercise, there have been numerous studies to suggest that compression apparel could also be used to aid recovery post exercise.

Although the benefits of selectively varying the mechanical properties of fabrics is clearly recognised, prior-art methods for implementing the changes desired by designers are unfortunately rather crude. These include the addition of panels of different materials by stitching or bonding, which introduces extra material, seams, physical inconsistencies and can be visually undesirable. Seams in panelled compression apparel can create an uneven modulus across the surface of the garment, which is particularly undesirable in sportswear applications where gradual compression is applied functionally to enhance athletic performance. Stitching and bonding operations also tend to be laborious and often require highly skilled technicians. For example, the fabric in the Speedo® suit described above was made by cutting and positioning material in different orientations; combined with different fabrics to create a panelled construction. This is highly laborious. Variation of knit pattern can also be employed, but this technique can only really be used to make large-scale changes to material properties, rather than customised local changes.

Surface application finishing techniques, such as printing of adhesives, can be used to control the elastic properties of stretch fabrics after construction, creating a simultaneous decorative effect. The pattern on the surface of the fabric relates directly to the elastic properties of the fabric, with a higher proportion of surface coverage restricting fabric stretch further. Fabric stretch can also be controlled in multiple orientations using this method depending on the pattern that is applied. A limitation of this technique is the application of additional materials in achieving the effect, which has a negative impact on product cost. There is also the
likelihood that any surface application would be subject to wear and delamination over time.

Laser processing has also been used in the textile industry for modifying various material properties in specialised applications and also for joining and cutting. For example:

US 5,529,813 describes a method for laser microstructuring of individual fibres by production of wavy micro patterns, particularly to alter the visual appearance and tactile aesthetic of the fibres. The method is deliberately carried out in such a way that there is no significant effect on the fibre physical properties.

US 5,017,423 describes laser microstructuring of textiles, including individual filaments or flat articles, whereby they can be textured/roughened for improved adhesive properties, altered frictional properties, patterning, microporosity/permeability, chemical modification and static reduction. The method of this patent is directed to production of microscale features and is not generally applicable to those features readily visible to the naked eye (macroscale/macroscopic features).

EP 1 117 502 describes forming a transmission laser weld in polymers using a visually transmissive absorber at the joint interface in place of a visually prominent absorber, such as carbon black, normally used in transmission laser welding techniques. This can include sheets and textiles. However, this method and similar transmission laser welding techniques known are directed toward the joining of materials to construct larger articles. Laser joining of fabrics is considered as being deleterious to mechanical properties due to the properties of the welded seams.

In light of the prior art, it is an objective of the invention to provide a new method for modifying the elastic modulus of materials, particularly in a highly controllable manner and which avoids some of the drawbacks of known techniques.
Summary of the Invention

In accordance with a first aspect of the invention, we provide a method for selectively modifying an elastic modulus of a process region of a textile substrate, comprising exposing with a power beam a plurality of sub-regions, within the process region of the substrate, so as to cause melting and coalescence of the textile fibres within each sub-region, such that at least one elastic modulus of the textile within the process region is modified with respect to the said at least one elastic modulus of the process region prior to the exposure of the sub-regions to the power beam, and wherein the modification of the at least one elastic modulus is dependent upon the combined effect of the exposure of the plurality of sub-regions to the power beam, wherein the textile substrate comprises an elastic fibre content.

We have realised that a power beam can be used to selectively modify the elastic modulus of an extensive process region of a textile substrate. For example such a region may have an area of tens of square centimetres and therefore may be of a sufficient scale to modify the fit of a garment upon a wearer or to provide support or compression to a part of the body of the wearer. This modification of the elastic modulus of the process region may be achieved by the treatment of a number of sub-regions with the power beam with these sub-regions being typically distributed across the process region. The elastic modulus of the material in the sub-regions is typically modified significantly. It is the cumulative effect of the local modification of the elastic modulus in each sub-region, together with the number of such sub-regions in the process region as a whole, together with the distribution of the sub-regions which causes the resultant elastic modulus of the process region. Specifically, melting and coalescence of the textile fibres is such as to cause entrapment of the elastic fibres within the textile substrate, thereby limiting movement of the elastic fibres. The elastic modulus of the melted textile region is therefore measurably higher than the non-melted region of the textile substrate.

The invention includes methods for modifying the elastic modulus of textiles, typically containing polymer-rich elasticated fibres, using controlled melting and
fusing of textiles fibres, together with associated methods for designing, shaping and manufacturing garments and other end products.

In comparison to the methods in US 5,017,423, where the scale of modification is on the microscale (in that case on a scale smaller than that of an individual fibre width), in the present method the modification is "cross-fibre" in that melting and coalescence of the fibres takes place, which is carried out in a pre-determined fashion to impart a controlled change in the elastic modulus of the region as a whole.

As will be understood there are a number of different elastic moduli of a material. The elastic modulus may be one or more of Young's modulus, shear modulus and bulk modulus. In most cases the nature of the material properties of the textile substrate will mean that more than one such modulus is modified as a result of the method.

The power beam used in the invention may take any appropriate form provided it is capable of causing melting and coalescence of the textile fibres. Such a power beam may be an electron beam or an ion beam. Preferably the power beam is a laser beam. Typically the laser beam emits radiation in the infrared part of the electromagnetic spectrum (700nm - 1mm wavelength), most preferably in the wavelength range of 800 to 11000nm. Use of lasers emitting radiation at these wavelengths allows efficient absorption and conversion of energy either directly by textile substrates or via absorber materials disposed within/on textiles, into thermal energy causing melting. Infrared lasers have been found to be most advantageous in terms of the efficient absorption of the laser radiation by substrates and absorber materials and generation of heat causing melting, their ubiquity, ease of manipulation and affordability.

Textile substrates in this case are defined as being composed of fibres arranged in various forms including filaments, monofilaments, yarns, threads, of similar or different types in the fabric or other such commonly used materials in the textile industry, and may be woven, knitted or non-woven. Textile substrates suitable for implementing the invention should melt, at least locally at the fibre level
(before pyrolysing or igniting) when sufficiently heated. The textile substrate is preferably formed from fibres comprising a polymer material. Typical textile substrate materials include those with a high thermoplastic content, containing thermoplastic fibres such as nylon (a polyamide), polyester, acrylic, polypropylene or polyethylene. These can include textiles with a natural or non-thermoplastic content, but a substantial melting fibre fraction is preferred. The textile substrate also contains an elastic fibre content, such as polychloroprene, neoprene and rubber. Preferably, the elastic fibres comprise elastomers. Further preferably, the elastic fibre content comprises one or more of polyurethane, elastane, polychloroprene, neoprene or rubber. Therefore, particularly suitable textiles include those typically deemed as 'stretch fabrics', either 2-way or 4-way stretching, such as elastane, spandex (sold under trade marks such as Lycra, Elaspan, Acepora, Creora, INVIYA, ROICA, Dorlastan, Linel, ESPA).

As discussed above, fabrics may be constructed from synthetic and natural fibres of different kinds, using knitting, weaving or non-woven construction with the fibres of utility generally being synthetic forms, and the sub-set of those being forms which may be melt-processed. These may be mixed in the construction of a fabric with other fibres which may be natural types, or other synthetic types including elastomer fibres such as Lycra. Typical fibres and fabric construction methods are described in 'Joining Textiles, Principles and Applications', Edited by I Jones and G Stylios, 632 pages, Woodhead Publishing Ltd (31 Jan 2013), pp2-28.

The fibres in a fabric are usually used in multi-filament yarn forms, although elastomer fibres may be included singly i.e. as mono-filaments, in combination with yarns of the other fibres. For example, Lycra is an elastic filament that produces fabrics that are highly extensible with good recovery characteristics. The percentage of Lycra has an effect on the elastic behaviour of the fabric. Elastic modulus increases with Lycra content, assuming that the surrounding fabric is constructed using a knit or weave that is easily extensible. Fabrics with high percentages (5-25%) of Lycra are used for compression apparel. Compression fabrics are used for the construction of shapewear garments and more recently in sportswear.
In laser treatment of the fabric discussed here, some of the melt-processable synthetic fibres are melted in a controlled fashion. The melted fibres in contact with each other become locked together and their movement is restricted, hence altering the elastic properties of the fabric. The desired effect may be obtained without melting the full thickness of a fabric or all the fibres in a particular fibre bundle or yarn, as discussed further later. Elastomer mono-filaments in the fabric, although they may not melt, may also have their movement restricted by the melting of surrounding fibres. In some embodiments, the power beam is controlled specifically such that the elastic fibre content substantially does not melt and the melted and coalesced fibres surrounding the elastic fibres restrict their movement. In view of the present disclosure, the skilled person will be able to select appropriate variables for achieving this non-melting of the elastic fibre content, which, as discussed below, include variables such as the transparency of the elastic fibre content, the elastic fibre material used, the beam power density, pulse lengths and traverse speeds.

The power beam and the material of the fibres are preferably selected such that at least 80% of the energy of the power beam is absorbed by the fibres. It is preferred therefore that the textile substrate materials are transparent to less than 20% of the power beam radiation; that is 80% should be absorbed. If the workpieces do not absorb more than 80% of the energy, then it is advantageous to use an absorber material added to either the body or surface of the textile workpiece. Such absorber materials could be carbon black, the additives mentioned in EP 1 117 502, or, for a laser power beam, any other absorber generally known within the art of transmission laser welding. Alternatively, highly absorbing and less absorbing materials can be used in conjunction, for instance in a multi-layer fashion. This also allows the possibility of creating a unique aesthetic using different material types with different visual characteristics (colour, transparency, weave), or if the elastic modulus changes are to be made with no outward visible change to the fabric, or using materials with very different performance characteristics, such as novel combinations of materials with different elastic moduli.
The power beam parameters used in accordance with the invention can vary greatly depending upon the degree of processing required by a particular substrate and to provide the required physical effect for different applications, and include variations in beam power, spot size, traverse speed and beam pulse length.

It is preferred that the power beam density on the textile substrate is greater than 1Wmm⁻², however in some cases the power beam density on the textile substrate may be less than 1Wmm⁻². Typically the beam power output used is less than 200W, preferably between 10W and 100W. The typical spot size of a beam width is between 0.1 mm and 20mm, more preferably between 1 mm and 4 mm in a spot geometry which has similar dimensions in orthogonal directions in the beam cross section (such as is the case for a circular beam cross section).

Typical beam pulse lengths generally depend upon the traverse speed of the beam and the effect required (which of course depends upon the substrate), but can be varied to provide a pattern of melted and non-melted regions on the fabric. The marking and spacing of the pattern defines the degree of change imparted in the fabric properties. The marks (sub-regions) may be arrays of spots, lines of spots, or continuous lines. The spots may vary from circular to elongate or any shape form, including cross-shaped, V-shaped, ring-shaped and/or open circle forms. The spots and spot spacing may have dimensions in the range 0.1 mm to 20mm, even up to being continuous lines, though would preferably have dimensions in the range 1mm to 4mm. Preferably, the spots (and spot spacing) have a maximum dimension of no more than 20mm, preferably in the range 1mm to 4mm. Additionally, the spots preferably have a minimum dimension of at least 0.1 mm, more preferably at least 1mm. Where the spots are continuous lines, the lines may be straight, wavy or may have more complex forms.

Although the sub-regions could be distributed randomly within the process region, it is beneficial for controlling the overall elastic modulus of the process region if the sub-regions are provided as a pattern within the process region of the substrate. One or each of the pattern and the shape of the sub-regions may
be controlled to provide a different elastic modulus in different directions lying within the plane of the textile substrate. Preferably the sub-regions are distributed across the region of the substrate in a regular pattern. Whilst each sub-region may be of the same shape the sub-regions may be of different shapes, for example different shaped regions may be provided at different locations in the "motif of a repeating unit mesh pattern. In the case of asymmetry within the geometry of the sub-regions then the orientation of some sub-regions may also be arranged differently from others.

For example, each of the sub-regions may take the form of spots having a dimension in the range 0.1 to 20mm. Some or each of the sub-regions are elongate having a preferred maximum dimension in the range 1 to 4mm. The power beam parameters are determined by the required form of the melted regions on the fabric. A typical pattern may be a series of lines (sub-regions), which may be continuous or discontinuous; the lines may be straight or curved. The elastic modulus will be increased more along the direction parallel to the long axis of the lines than across the lines.

The substrate in a sub-region has a thickness and generally the power beam is arranged to cause only part of the material to be melted in the sub-region within the through-thickness direction. Typically the melted sub-regions should be shallow and should not melt through the full thickness of the textile substrate. The beam parameters are generally set to provide the correct desired effect and to provide the required pattern of melted regions on (or within) the fabric. The pattern in turn is defined by the changes required in the elastic modulus. This typically includes the magnitude and direction of the changes in the elastic modulus.

Whilst we have derived relationships for certain fabrics between the pattern of marks (sub-regions) and process parameters and the elastic modulus of the fabric, it is feasible to provide a mathematical model of the property changes expected as a result of the power beam processing conditions.
The invention is equally applicable to single-layer and multi-layer textiles, or to treatment within a single layer. The power beam may be applied to sub-regions within the process region upon each side of the textile substrate. When the textile substrate is formed from a plurality of layers the exposure to the power beam may be arranged so as to cause the fusing of at least two of the layers in the sub-regions. Thus, in multi-layer textiles, the invention can be applied independently to each side or performed from one side, where the degree of melting causing fusing of at least two layers. For lay-ups of greater than two layers, if it is not possible to penetrate deeply enough from one side, then the invention may be applied from both sides to cause mechanical modification and join multiple layers from each side. Treating the interior of a textile is preferably enabled if the textile has been constructed with fibres or imbibed with absorber such that the interior has increased absorption for the laser source compared with the rest of the textile. The interior melting may be carried out with less alteration to the outward appearance of the textile, similar to the effect of fusing two layers.

The invention provides the ability to achieve the controlled modification of the elastic modulus of one or more regions of textiles. In contrast to techniques used for joining materials by fusing of material layers using a power beam, where the minimum possible number of joints is generally made to fulfil mechanical performance criteria whilst avoiding changes to textile property as much as possible, with the present invention generally a far greater number of melted features (sub-regions) are provided in discrete areas. Typically these are applied in a unitary or single workpiece rather than a power beam being used to join multiple separate workpieces.

The melted and coalesced fibres of the sub-regions may comprise a total area density in the range 7-80% of the total area of the region. More preferably the area density is 15-50%.

Using this approach, fabric stretch can be controlled in multiple directions. The orientation of the sub-regions of melted lines or spots defines the direction of the maximum and minimum change in the elastic modulus. As mentioned above the
modulus is increased more if the density of the melt pattern is more in that direction. In the extreme case the melted sub-region may be a continuous straight line, which provides the greatest increase in elastic modulus along the line. By patterning the melting in different ways, the magnitude of the change in elastic modulus can be controlled in any given direction. The elastic modulus of a process region may generally be increased by a factor of up to five.

To assess the modulus, typically an area of fabric to be tested is cut into a rectangular coupon based upon the direction in which the determination of elastic modulus is required (aligned with the longer dimension of the rectangle). The size of the coupon is also of course dependent upon the size of the region in which modification of modulus is to be sought, but typically a coupon with a width of at least 25mm and length 150mm is used if possible. The thickness of the material is measured and is assumed to be the same throughout the coupon. The coupon is clamped in the jaws of the testing apparatus with the length of coupon between opposing jaws, where the jaws firmly clamp the full width of the coupon (without tearing) whilst presenting around 100mm of material between the opposing jaws before testing commences. The coupon is then pulled and released three times at a constant rate to obtain average readings of force (N) at a particular extension, and, extension (%) at a particular force during a single test cycle. For a typical swimwear fabric, a testing rate of 500mm/min would be used with measurement of force at 40% extension and extension at 36N during a single test cycle. Of course, different fabrics would often require different parameters dependent upon their pre-existing mechanical properties. For instance, very fine fabrics would require less force and more extension, whilst heavy fabrics may require more force and less extension to obtain sensible test results. Determination of these testing parameters is well within the ambit of the person skilled in fabric testing, and more broadly within the field of mechanical testing. Knowledge of the strain at a given stress and stress at a given strain, together with the dimensions of the material, allows the calculation of the modulus of the material forming the coupon. In the test described the Young's modulus (or linear modulus) is most simply calculated.
The discussion of the material modulus here is in the sense of the macroscopic modulus of the process region which is the result of the combined effects of the modification of the modulus in each of the sub-regions. Thus it is the cumulative or average modulus of the processed and unprocessed regions present within the coupon. Whilst it is possible to use other techniques for measuring the macroscopic modulus of the material, the principle underlying all such techniques is that the volume of the material included in the test coupon is significantly larger than the volume of each sub-region. Of course, generally this volume comparison can be thought of as equivalent to a surface area comparison (given that a significant proportion of the thickness of the material is modified by the process in the sub-regions). In general the coupon acting as the test piece is of a size such that the volume of each sub-region is less than 20% that of the coupon. We note here that this is independent of the percentage of material within the process region as a whole that has been processed (and therefore forms part of a sub-region). For example, if a coupon has an area of 2500mm², it may have a total of 50% of the material having been processed as sub-regions. However, if each region is a square of 10mm by 10mm, then the percentage area occupied by one sub-region is 4%.

The technique can also provide visually appealing appearance by careful design of the patterns used, whilst also changing the feel of the fabric surface and the experience of the wearer if it is a garment. Examples include swimsuits, cycling garments, outdoor wear, skiing garments and other sports garments.

Varying the distance between and orientation of melted lines or using pulsed laser (or other power beam) processing allows the proportion of surface melting to be controlled, also allowing control of the elastic properties of the fabric as a whole, including the magnitude and direction of the changes in elastic properties. The required pattern for a given application is defined by considering the need (thrombosis, sports recovery, streamlining etc.), the fabric and garment type (shirt, sock, etc.) and the size/shape of the wearer, which may be defined by 3D scanning in customised cases or from garment size charts in generic cases. The definition of the melt pattern required to develop the elastic modulus changes can be carried out using trial and error, whereby different melting patterns and
densities are trialled on textiles, or by mathematical modelling. Mathematical modelling may take the form of overlaying known modification pattern results with required changes in textile properties.

In some cases, the textile substrate is provided with a power beam transparent cover layer through which the sub-regions are exposed to the power beam. The process steps mentioned above are therefore carried out with a smooth, power beam transparent sheet pressed over the textile. In the case of laser power beams, typically a polymer such as PMMA is used, although certain types of laser-transmissive glass or plastics are also of utility). We have found that this provides an attractive surface 'shine' to laser melted features. It is also beneficial in reducing the projection height of the features in the sub-regions above the plane of the untreated substrate surface which is particularly beneficial when considering the application of other layers of material to be overlaid upon the process region.

In a second aspect of the invention we provide a method of creating a modified textile substrate for use in a garment, comprising:

a) identifying a process region of a textile substrate of a garment in which the elastic modulus of the textile is to be modified;

b) selecting one or more modification parameters defining the intended modification to the elastic modulus in the process region;

c) selecting a set of process parameters suitable to effect the defined modification according to the selected modification parameters; and

d) using a method according to the first aspect of the invention, according to the selected process parameters, to effect the modification of the textile substrate in the process region.

The method can be used to great advantage to create a customised garment, whereby:

1) either the wearer or an artificial model is used to identify the areas in which modification of elastic modulus should be applied;

2) the necessary parameters are set and

3) power beam processing is then performed.
Step (a) can be carried out using a traditional technique, such as by performing a 'fitting' of a garment (containing a textile substrate) by a skilled technician. Here the technician manually identifies areas that require greater elasticity (where material gathers in a garment; around areas such as joints, buttocks, back, chest, arms, legs, neck, etc.). These areas may also be identified via semi-automated or fully-automated techniques involving 3D scans, computer models and the like which perform equivalent tasks to the more traditional techniques.

Steps (b) and (c) may include the selection of suitable materials, the testing of these materials for suitability, performance of initial trials, mechanical trials and either selection of power beam parameters from an established matrix, or development of new parameters.

Step (d) is typically carried out using the developed parameters, which may then be subject to testing and feedback-looping of parameters through various iterative steps until the desired outcome, including the achievement of the desired elastic modulus in the region is achieved.

Preferably therefore one or each of step (a), step (b) or step (c) are performed by the use of a computer model of the mechanical behaviour of the garment when subjected to the processing of the sub-regions.

With reference to the use of mathematical modelling, once the required changes in elastic modulus are known (from information described above about the need and shape of the garment and wearer), then this map of elastic properties may be transferred to a 2D textile form. The 1D changes in elastic properties for a given fabric are measured experimentally following a series of power beam treatments at different processing conditions. From these results, and from knowledge of the physical properties of the untreated fabric, a model may be developed which provides an output of the elastic properties of a 2D fabric sheet for any pattern of dots or lines of power beam treatment on the surface. From a series of runs of the model the power beam treatment required to create the required map of elastic properties is identified and may be recreated physically.
Typically the method further comprises a step (e) of forming a garment using the processed textile substrate in which the elastic modulus of the process region has been modified.

In accordance with a third aspect of the invention we provide a textile modification system for selectively modifying an elastic modulus of a process region of a textile substrate, the system comprising:

5 a support against which the textile substrate is located when in use;

10 power beam emission apparatus arranged to direct a power beam onto a process region of the textile substrate located against the support, wherein the power beam emission apparatus and the support are arranged to be relatively moveable such that the power beam may expose a number of sub-regions within the process region; and

15 a control system adapted to expose to a power beam of the power beam emission apparatus a plurality of sub-regions, within the process region of the substrate, so as to cause melting and coalescence of the textile fibres within each sub-region, such that at least one elastic modulus of the textile within the process region is modified with respect to the said at least one elastic modulus of the process region prior to the exposure of the sub-regions to the power beam, and wherein the modification of the at least one elastic modulus is dependent upon the combined effect of the exposure of the plurality of sub-regions to the power beam.

20 The system according to the third aspect of the invention is preferably adapted to perform the method according to the first or second aspect.

The power beam emission apparatus is typically a laser, such as an infrared laser. The system may further comprise a clamp for urging the textile substrate against the support. The system may also further comprise a power beam transparent sheet adapted to be urged against the surface of the textile substrate such that the power beam passes through the transparent sheet and is incident upon the surface of the textile substrate. This sheet may be held to the support by the clamp so as to urge the textile substrate against the support.
Some of the advantages of the invention are that it can:

- Provide variable levels of compression across a single fabric layer;
- Help avoid harsh divisions between different zones of compression;
- Reduce the use of labour-intensive methods;
- Control fabric stretch in multiple directions;
- Provide textiles/garments with a visually appealing appearance; and
- Provide a shaping effect on the body resulting in improved streamlining in air or water.

Other advantages are that products manufactured using the methods according to the invention typically do not require the use of additional materials such as textile panels and layers. The invention is therefore advantageous in that it does not add weight and instead modifies an existing piece of fabric, rather than by using additional fabric pieces to modify garment characteristics. Techniques according to the invention provide high repeatability for production in industry and reduced labour utilisation when compared with existing techniques for elasticity modification. Furthermore, unlike surface application techniques, the properties imparted by the invention will not delaminate or wear substantially during normal use.

**Brief Description of the Drawings**

Some examples of the method according to the invention are now described with reference to the accompanying drawings, in which:

- Figure 1 shows an example of suitable apparatus for use in performing the invention;
- Figure 2 shows an example method of using the apparatus;
- Figure 3 shows examples of different processing patterns typical of the invention;
- Figure 4 shows a schematic illustration of patterned areas on a garment processed according to the invention;
- Figure 5a shows an example of a torso in an unprocessed garment;
Figure 5b shows an example of a torso in a garment processed according to the invention; and Figure 6 shows a medical compression garment.

5 **Description of Embodiments**

We now provide a detailed explanation of the invention. Firstly some suitable apparatus is discussed, together with the method of its use. We then discuss an example application of the method in the processing of swimwear textiles.

10 Figure 1 shows an example apparatus used to perform example methods according to the invention. A moving flatbed worktable 3 is moveable in an XY plane normal to a laser beam from a laser emission source 5. The laser emission source is arranged to direct a laser beam towards the flatbed worktable 3 so as to provide normal incidence of the beam on the worktable 3. A 150W diode laser (manufactured by Laserline GmbH, Germany) is used as the laser emission source 5 with a wavelength of the emitted radiation as 940nm (infrared). The laser emission source 5 may be provided on a moveable mounting system also. A clamping mechanism 4 is mounted to the laser emission source 5 between the laser emission source 5 and the worktable 3. The clamping mechanism 4 has an aperture in the centre to allow transmission of the laser from the laser emission source 5 to the worktable 3. In this case the clamping mechanism is a ring clamp with a 30mm ring and 10mm aperture.

When in use a textile substrate is laid out in a flat configuration upon the surface of the flatbed worktable 3 such that the laser beam can be emitted from the laser emission source 5, pass through the aperture of the clamping mechanism 4 and impinge upon the textile substrate. The function of the clamping mechanism 4 is to ensure that the textile substrate is held in a flat configuration during processing by the laser. This also ensures that the desired locations (in the XY plane) are accurately located with respect to the laser beam.

In the present example the clamping mechanism 4 is rigidly oriented with respect to the laser emission source 5. The movement of the flatbed worktable 3, the operation of the laser emission source 5 and all other components capable of
automated operation are operated under the control of a control system 10. The clamping of the textile substrate to the surface of the flatbed worktable 3 is achieved by the relative movement, in a Z direction parallel to the laser beam direction, between the flatbed worktable 3 and the laser emission source 10 under the control of the control system 10. In order to clamp the textile substrate to the flatbed worktable 3 the flatbed worktable 3 is brought towards the clamping mechanism so that a small gap of about 1-2 mm exists between them. This causes the textile material to be trapped between clamping mechanism 4 and the flatbed worktable 3.

A spray unit 8 is also shown in Figure 1 which is used for delivering an infrared absorber material when required. The operation of the spray unit 8 is under the control of the control system 10. The spray unit 8 includes an absorber within a mechanically operable syringe 6 to act as a supply for the absorbed liquid, together with a spray head 7. The spray unit 8 is capable of providing a coverage of absorber liquid over a region of the textile substrate which is significantly larger than the laser beam diameter. In this case the spray unit 8 is mounted such that the local area of any textile substrate that it supplies with absorber does not coincide with the point of impingement of the laser beam. In use the absorber is typically used to treat the entire process region of the textile within which the laser is to be applied at multiple locations within the process region. The treatment by the absorber is applied to the entire region at an earlier time than the processing by the laser.

Although not shown in Figure 1, a laser transparent coversheet may also be used. Following any application of the absorber material by the spray unit 8 and a subsequent drying stage, the transparent cover sheet may be pressed over the entire textile substrate surface to be treated. The function of the transparent coversheet is to alter the surface finish of the textile substrate, as described earlier. When using the transparent coversheet, the system controller 10 modifies the gap between the clamping mechanism 4 and the flatbed worktable 3 to accommodate the additional thickness of the transparent coversheet and it is usually the case that the moving clamping mechanism 4 does not contact the transparent coversheet, or if it does it may be provided with a surface or
covering that does not scratch or otherwise damage the transparent coversheet. In the case that the moving clamping mechanism 4 does not contact the coversheet, the coversheet itself may be clamped to the worktable at its edges by an alternative clamping mechanism.

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As an alternative to the system described above, other apparatus could be mounted on various well known manipulation systems, including articulated robots.

10 We now describe the steps of an example method of using the apparatus of Figure 1 so as to process a textile substrate and modify its general elastic properties across a particular defined region. The method is discussed in association with Figure 2.

15 As an initial step 100 in Figure 2 a textile substrate, typically already forming part of a garment, or to be later incorporated into a garment, in each case for a desired purpose (body shaping, compression, and so on) is analysed to assess its suitability to undergo modification of its elastic modulus properties. Typically this includes acquiring basic information upon the type or types of material used in the textile substrate. Assuming such materials are potentially suitable for processing, for example the material may be formed from fibres of thermoplastic polymer, then step 100 may include measuring the transparency of the textile substrate workpiece to the radiation emitted by the laser emission source 5. This may be achieved using an energy meter. A measurement of the energy received by the energy meter with the laser incident upon it may be made in the presence and absence of the textile substrate when positioned between the laser emission source 5 and the energy meter. It is contemplated of course that a laser emission source with a different laser wavelength may be used if the textile substrate exhibits better absorption at such a different wavelength. In the event that the energy meter indicates that insufficient absorption of the laser beam will occur then step 100 may also include the selection of a suitable absorber to increase the energy absorbed by the material.
At step 110 a process region of the textile substrate is selected for modification of its elastic properties. The selection of such a region, or indeed more than one region, is particularly important when considering a garment as a whole within which the textile substrate has already been incorporated, or may be incorporated later. The selection is dependent upon the desired use. This step may be performed in a number of ways. For example, in the case of swimwear a designer of the garment may wish to increase the elastic modulus around the thighs of the wearer to provide great support to the thigh muscles. The aim may be for example to increase the elastic modulus in the material by 15% in an approximately circumferential direction around the thigh of the wearer. Nevertheless they may wish the elastic modulus in adjacent regions at the top of the leg and nearer the knee of the wearer to remain substantially unchanged. This might particularly be the case where a unitary "single piece" of textile material is used for all of these regions of the leg, and potentially the rest of the garment.

At step 120, having selected the extent and nature of the change in the elastic modulus required for the region as a whole, the method proceeds to consider how this is to be achieved in practice by the selection of modification parameters. This step generally involves the selection of a suitable pattern of a number of sub-regions in which to apply the laser beam so as to cause the macroscopic modification of the elastic properties across the larger process region. The pattern is typically regular, such as an array, and it will be appreciated that the spacing between the sub-regions in each dimension will affect the elastic properties of the region as a whole. Likewise, the geometry of each sub-region will affect these properties.

A human process designer having some experience in the use of the present process may be able to select a suitable pattern, together with a suitable form of each sub-region or groups of sub-regions so as to achieve the desired effect. For example a square grid pattern (therefore with orthogonal pitch and equal pitch spacing) may be initially selected in which the dimension of each sub-region is 30% of the total pitch length in each of the orthogonal directions. This will produce a small increase in the elastic modulus in each of these orthogonal
directions across the whole region in question. Taking one of these dimensions as an example, and defining this the X dimension which will be aligned with the circumferential direction around the thigh of a wearer of the garment, the application of the process in a grid pattern to these sub-regions will cause the elastic modulus to be increased by a relatively small percentage (remembering that only 9% in area is actually treated for this pattern), equally in the X dimension and the dimension normal to that (which we shall denote the Y dimension). To increase the elastic modulus further in the X dimension then one can either reduce the pitch in that dimension, or elongate the sub-regions along that dimension, or each of these. Nevertheless, because the elastic modulus is a tensor property, the modification in elastic properties in one dimension is not independent of those in other directions (including the Y direction and the through-thickness direction). The relationship between the pattern and its sub-regions to the overall elastic properties of the process region quickly becomes complex once any complexity is built into the pattern or the shape of the sub-regions, or each of these. A further complexity occurs if the textile substrate material itself, prior to any treatment, is anisotropic in its elastic or other mechanical properties. This is often the case.

This process at step 120 may therefore be assisted by the use of computer modelling. For example a computer model may be generated of the textile substrate to analyse the behaviour of that substrate when different patterns and sub-region geometries are applied. One technique for achieving this is the use of finite element modelling which allows an accurate calculation of the complex effect of the sub-region processing upon the elastic properties to be achieved. The design process for the regions may therefore be computer-assisted in that a user may use the computer model to monitor the effect of changes to the pattern of sub-regions. Furthermore, the computer model may be used within an iterative automated (unsupervised) model which iteratively modifies one or more "seed" patterns in an attempt to achieve a set of desired elastic modulus properties for the process region.

For example, starting at a square array of sub-regions with a given sub-region area density the model may modify one or more of the parameters describing
the pattern, including the geometry of the sub-regions or groups of different sub-regions so as to arrive at a solution for the required elastic modulus properties.

In a more advanced model, the properties of the laser beam and the material itself may be included such that the predicted solutions may include specific laser beam parameters such as the power density to apply to the sub-regions in a given area for a given time and so on.

At step 130 the method proceeds by selecting the process parameters. These can be thought of as the specific control parameters that define the process to be performed. For example these include the laser power density, the duration and travel time of the laser, parameters defining the pattern arrangement and the geometry of the sub-regions together, if necessary, with other parameters defining the type of substrate, the type of any absorber and so on. Essentially the process parameters can be thought of as the parameters which define the process which is to be applied. It will be understood that some of the process parameters may result from any computer modelling that has been performed, with others being defined by the type of equipment being used to perform the process.

At step 140 the textile substrate is laid on the upper surface of the flat worktable 3 and moved relative to the worktable 3 such that the region to be treated is correctly positioned with respect to a datum or other system coordinates for use with the control system 10. Although the worktable of Figure 1 is flat, we note here that curved surfaces are also possible for use with laser manipulation equipment having the capabilities of treating textile substrates on such a surface (e.g. using a robot arm).

In the present example at step 150 the process requires that the region of the textile substrate is pre-treated with an infrared absorber. This is applied by the system controller 10 moving the worktable 3 whilst operating the spray unit 8 so as to provide an even coverage (for example using a raster path) of sprayed absorber liquid over the entire region of the textile substrate to be processed. An advantage of the spray unit 8 being mounted to the laser emission source is that,
alternatively, the spray unit 8 may be used to treat only the parts of the region which are to form the sub-regions. The pre-treatment may be carried out by spraying, for example, 100nl/mm² of Clearweld LD120B infrared absorber, available from Gentex Corporation, or an appropriate equivalent. Once this has been achieved there may be an optional delay step to ensure that the absorber material has dried.

At step 160 optionally a smooth, laser transparent sheet may be placed over the textile substrate so as to cover the region to be processed (typically PMMA 3mm thick is used, although glasses or other plastics may also be used). Once in position a clamp is applied to clamp the coversheet to the worktable 3. This may be a fixed (at the edges or otherwise), moveable or sliding clamp, with aperture(s) to allow the laser to pass through. When, for example using clamps fitted to the edges of the coversheet, this presses the coversheet and compresses the fabric below it. In this way, the fabric is compressed while it is treated, and the upper surface of the melt is pressed against a flat surface as it cools. A smooth surface on the clamping sheet gives the treated textile a very smooth shiny surface. The clamping sheet may also be provided with a selected texture of different forms. This texture would be transferred to the fabric surface upon melting, and could give the textile a matt or patterned finish on the melted sub-regions as required.

At step 170 the processing of the sub-regions is performed under the control of the system controller 10. In the present case each sub-region, which initially is merely a location upon the unmodified substrate, is then subjected to the application of the laser. Each sub-region is processed by moving the flat worktable in its XY plane so as to align the sub-region with the point of incidence of the laser beam. When aligned in the correct location the laser beam is turned on by the control system and, depending upon the shape of the sub-region desired, either allowed to dwell whilst static for a predetermined period, or the worktable 3 is moved so as to cause the movement of the laser at a particular velocity along an interaction path across the surface of textile substrate in the sub-region, the path defining the shape of the sub-region, which may be linear, curved or an even more complex shape.
As will be appreciated the laser treatment is conducted according to the process parameters so as to the sub-regions through combined manipulation of the table and/or laser source and by turning the laser on and off in synchrony with the manipulation). During the processing of a sub-region the laser may be pulsed if this produces a beneficial effect. Each sub-region is processed in turn, in this case by applying the laser beam through the transparent coversheet. Thus the focus of the laser beam is adjusted in cooperation with the separation distance between the laser emission source 5 and the textile substrate, this accommodating the coversheet thickness.

If the coversheet were not present and the clamping mechanism 4 was used instead then the movement between each region may also require a movement in the Z direction parallel to the laser beam so as to clamp the textile substrate to the worktable 3 by moving the clamping mechanism into contact with the textile substrate, followed by the removal of the clamping mechanism from the textile substrate so as to allow easy lateral movement to the location of the next sub-region. It is possible that a combination of clamps, such as fixed and moveable may be used, dependent upon the size and configuration of the textile substrate.

Following the processing of all of the sub-regions within the desired process region, the textile substrate is removed from the apparatus at step 180.

Once removed the textile substrate may be in a state which may be ready for wearing by a user. This is particularly the case if the substrate were already part of a constructed garment. Following the process described above further additional processes may be performed upon the textile substrate at step 190. These might include the incorporation of the processed region into a garment by one of a number of known methods. Other finishing processes could also be performed, for example to apply further coatings or additional layers. It is also contemplated that one of the processes may be a further application of another laser treatment process analogous to the earlier steps. For example if one side of the textile substrate were treated by the process then one further process might be the treatment of the other side.
One of the most advantageous applications of the present invention is in the development of garments that compress the body assisting muscle and circulatory system operation and in shaping for streamlining, for example in sportswear. Controlled use of pre-defined patterned melting, using straight and curved forms at different orientation to the fabric manufacturing direction can be used to manipulate the elastic behaviour of the fabric and hence the movement of the body during athletic activity, providing resistance to targeted muscle groups. This could be used to improve body positioning for optimum performance in many disciplines. Compression clothing for sportswear can be modified using the invention to provide targeted support to specific areas and muscle groups. This can improve sweat wicking, help relieve pain from muscle/joint stiffness, reduced fatigue and reduce the time taken for muscle repair, hold padding/undergarments in place and reduce the likelihood of sliding injuries. The degree of compression required varies by the area of the body. Typical regions benefiting from increased compression include the stomach, lower back, shoulders, chest and major leg/arm muscle groups. Compression can improve limb stability when recovering from injury (e.g. knees, ankles, elbows, wrists), buttocks (strain recovery).

The procedure to alter the fabric properties may be implemented using equipment that is industrially available now. The basic components of the equipment for a laser processing system include a laser with suitable absorption properties at the surface of the fabric to be processed. This may be a CO₂, fibre, diode or Nd:YAG laser (or others). The absorption may be enhanced by using a suitable radiation absorbing additive either applied on to existing fabric or as an additive within the fabric (a coating, dye or pigment). The patterning of treatment on the fabric is defined using programmable motion systems such as a gantry to manipulate either the fabric or the laser, or optical scanner to move the laser source. Simultaneously the laser may be turned on or off by a controller to provide patterns of dots or lines in the required orientation or pattern. Alternatively, the patterning may be defined by the absorber coating, applied using a stencil or by patterned printing or spraying. Certain finishes may require the fabric to be pressed during melting. This may be achieved using a laser-
transmissive cover sheet and a clamp that applies pressure to the fabric surface at the same time as the heating is carried out. Alternatively, the fabric may be pressed between rollers directly after laser heating in the desired patterns, this being an example of a further process of step 190.

One of the most apparent applications of this work is in the development of garments that compress the body, assisting muscle and circulatory system operation and shaping, for streamlining for example. Using the knowledge and process methods developed, prototype swimsuits were prepared with surface modification applied to target zones on the suits.

Figure 3 shows an example of the pattern spacing on a stretch fabric processed using different laser pulse lengths. The melted regions 1 are formed in lines over a discrete area, with the regions of greater melted material density, appearing as longer dark regions, providing greater increase in elastic modulus. Each line melted region 1 in this case constitutes a sub-region.

Figure 4 shows the selection of particular regions 2 on a swimsuit where modifications to elastic modulus are required, and the approximate patterns (dense melted sub-regions) used to make those modifications to elastic modulus.

Figure 5a shows the profile of a person wearing an off-the-shelf, commercially available nylon (a type of polyamide)/elastane swimsuit.

Figure 5b shows the profile of the same person wearing the same swimsuit as in figure 5a, but with modifications to the elastic modulus of specific regions processed in accordance to the invention. As can be seen the abdominal region of the wearer has been drawn in which provides an improved hydrodynamic effect for the swimmer and also supports their core muscle groups.

Figure 6 shows a diagram of a compression stocking used in medical applications for support of varicose veins or for after surgery. The degree of compression applied needs to be different at different locations on the stocking.
This is indicated by the size and shading of the arrows, where the larger and
darker arrows indicate a higher degree of compression. These different
magnitudes of compression may be provided by using the textile modification to
control the elastic properties. To achieve this, the sock may be notionally divided
into a set of horizontal process regions (orthogonal to the general primary axis
running along the leg of the wearer). Each region may be processed with sub-
regions in the manner described above. If the sock is formed from a single piece
of material then the regions can be arranged such that the area density of the
sub-regions increases as a function of distance from the top of the sock.

Example Test Data for Swimwear Fabrics

We now describe some experimental data which is illustrative of the utility of the
invention, in this case relating to swimwear.

Three swimwear fabrics were subject to modification in accordance with the
techniques of the invention. The fabrics were constructed using either a knitted
or woven technique. The fabrics were blue or black in colour and made from a
high percentage of nylon with a smaller proportion of elastane.

The apparatus of Figure 1 was used for this. It will be recalled that this includes
a 150W diode infra-red laser with a primary wavelength of 940nm.

The workpiece (textile substrate) samples were initially tested for compatibility
with the laser method. This was achieved by measuring the transparency of the
workpieces to the radiation emitted by the laser using an energy meter (Ophir
Vega with 10A-P sensor head). A short pulse (30W, 100msec, 3mm spot size,
940nm) is emitted from the laser into the energy meter, firstly without, and then
with, the fabric present between the laser and the meter. The difference between
the two readings gives a measure of the fabric transparency.

Details of each of the three fabrics used in this example can be found in the
table below:
<table>
<thead>
<tr>
<th>Material Number</th>
<th>Colour</th>
<th>Construction</th>
<th>Composition</th>
<th>Proportion of laser energy transmitted (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Blue</td>
<td>Woven</td>
<td>80% nylon, 20% elastane</td>
<td>41.9</td>
</tr>
<tr>
<td>2</td>
<td>Black</td>
<td>knitted</td>
<td>80% nylon, 20% elastane</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>Black</td>
<td>knitted</td>
<td>80% nylon, 20% elastane</td>
<td>11.4</td>
</tr>
</tbody>
</table>

From these results, it can be seen that samples with material numbers 2 and 3 are suitable for processing without an absorber, whilst the sample of material number 1 would benefit from the use of an absorber. The absorber may be applied by spraying, or may be provided as a suitably absorbing material layer (e.g. in a multi-layer fashion).

To determine the parameters necessary to obtain the desired amount of melted material, which directly influences the amount of elastic modulus change, trials were carried out varying the laser power, process speed and beam spot size. Using a beam width of 4mm and a process speed of 5m/min, marking to the top surface of all the fabrics began to show at a laser power of 20W. The marking increased in width and adopted a wetter looking appearance as the power was increased, which suggested an increased level of melted material. Knitted fabrics started to show signs of deterioration at 70W with splits occurring to the surface of the material in melted regions. Woven fabrics showed signs of deterioration at much lower powers from 20W upwards and tore under minimal force applied by hand. Woven fabrics were eliminated from further investigation at this stage due to the damage caused to the strength of the parent material.

Using a beam width of 4mm and a laser power of 50W, as the process speed was increased it was found that the width of laser melted regions decreased, as did the wet-look appearance on the surface of the fabric. Signs of deterioration to the surface of the fabric began to show at speeds of 1-2m/min and below, with charring and splitting of the material surface.
Results of visual assessments following the laser trials are shown below for material number 3, on varying the power and travel speed:

<table>
<thead>
<tr>
<th>Mat. No.</th>
<th>20W</th>
<th>30W</th>
<th>40W</th>
<th>50W</th>
<th>60W</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Some marking</td>
<td>Visible melting at centerline</td>
<td>Extending melting over beam width</td>
<td>'wetter' look over beam width</td>
<td>Extensive 'wet' look, evident surface over-melting</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mat. No.</th>
<th>10</th>
<th>8</th>
<th>6</th>
<th>4</th>
<th>2</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Marking over centreline</td>
<td>Increased marking over beam width</td>
<td>Visible melting at centerline</td>
<td>'wetter' look over wider centre</td>
<td>'wet' look over beam width, some surface deterioration</td>
<td>Extensive 'wet' look, evident surface over-melting</td>
</tr>
</tbody>
</table>

Mechanical testing trials were undertaken on two workpiece lay-ups using a simple linear (continuously melted line) pattern, with the distance between the lines varied to alter the coverage (area ratio of processed to unprocessed material) and also on a pulsed-laser pattern, which can be used to very effectively and simply control the melt density.

The first workpiece lay-up was just a single layer of material number 3. The second workpiece lay-up was a double layer with material number 1 placed on top (near side to the laser) of material number 2.

For each laser variable a measurement of force, at an extension of 40%; and extension, at a force of 36N, was extracted by mechanical testing.
The mechanical testing procedure involved cutting three samples for each variable level so that an average reading could be calculated. Samples measuring 50 x 140mm were cut and clamped in a tensile testing rig. The fabric sample was pulled and released three times at a constant rate of 500mm/min to obtain an average reading during a single test cycle. Tensile tests were carried out in accordance with BS EN ISO 13934-1:2013. Where the patterns were linear or lines of spots, the tensile tests were carried out perpendicular to the treatment lines, except where the effects of orientation (using curved patterns) was specifically investigated.

The results revealed, for all three variables tested, that fabric extension reduced and the force taken to extend the fabric increased with an increase in surface melting, as shown in the tables below. The base parameters used were 50W laser power, 5m/min processing speed, laser beam size 2x2mm, with only one parameter varied at a time.

Single layer mechanical testing results for different power levels are shown below:

<table>
<thead>
<tr>
<th>Power (W)</th>
<th>Force at 40% extension (N)</th>
<th>Extension at 36N (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parent</td>
<td>0.95</td>
<td>205.0</td>
</tr>
<tr>
<td>30</td>
<td>2.6</td>
<td>105.1</td>
</tr>
<tr>
<td>40</td>
<td>3.3</td>
<td>92.6</td>
</tr>
<tr>
<td>50</td>
<td>3.5</td>
<td>83.9</td>
</tr>
</tbody>
</table>

Double layer mechanical testing results for different power levels are shown below:

<table>
<thead>
<tr>
<th>Power (W)</th>
<th>Force at 40% extension (N)</th>
<th>Extension at 36N (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parent</td>
<td>3.8</td>
<td>67.6</td>
</tr>
<tr>
<td>70</td>
<td>16.5</td>
<td>51.3</td>
</tr>
<tr>
<td>90</td>
<td>19.8</td>
<td>47.5</td>
</tr>
<tr>
<td>110</td>
<td>21.3</td>
<td>46.3</td>
</tr>
</tbody>
</table>
The effect of the distance between melt lines was measured, broadly showing that the force required to extend the fabric increased, and fabric extension decreased, the smaller the distance was between melt lines.

5 Single layer mechanical testing results for different distances between the melt lines are shown in the table below:

<table>
<thead>
<tr>
<th>Distance between melt lines (mm)</th>
<th>Force at 40% extension (N)</th>
<th>Extension at 36N (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>8.6</td>
<td>57.6</td>
</tr>
<tr>
<td>10</td>
<td>4.4</td>
<td>82.2</td>
</tr>
<tr>
<td>15</td>
<td>3.1</td>
<td>96.9</td>
</tr>
</tbody>
</table>

Double layer mechanical testing results for different distances between the melt lines are shown in the table below:

<table>
<thead>
<tr>
<th>Distance between melt lines (mm)</th>
<th>Force at 40% extension (N)</th>
<th>Extension at 36N (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>No reading</td>
<td>29.8</td>
</tr>
<tr>
<td>10</td>
<td>24.2</td>
<td>44.9</td>
</tr>
<tr>
<td>15</td>
<td>16.9</td>
<td>51.1</td>
</tr>
</tbody>
</table>

The effect of the laser pulse length (defined as the time the pulse is on) was measured, with the time between the start of each subsequent pulse (pulse repetition period) being 120 msec. For both lay-ups, the force required to pull the fabric increased and fabric extension decreased the longer the length of the laser pulses, with the extension decrease for the double layer preventing force measurement due to lack of extension.

Single layer mechanical testing results for different lengths of pulse are shown below:

<table>
<thead>
<tr>
<th>Length of pulse (msec)</th>
<th>Force at 40% extension (N)</th>
<th>Extension at 36N (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>3.7</td>
<td>90.1</td>
</tr>
<tr>
<td>50</td>
<td>6.5</td>
<td>63.8</td>
</tr>
</tbody>
</table>
Double layer mechanical testing results for different lengths of pulse are shown below:

<table>
<thead>
<tr>
<th>Length of pulse (msec)</th>
<th>Force at 40% extension (N)</th>
<th>Extension at 36N (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>No reading</td>
<td>39.1</td>
</tr>
<tr>
<td>50</td>
<td>No reading</td>
<td>32.6</td>
</tr>
<tr>
<td>70</td>
<td>No reading</td>
<td>27.2</td>
</tr>
</tbody>
</table>

5 The surface melting effects of the invention have an effect on the tensile strength of the workpieces treated, with some decrease shown. This decrease in strength can be successfully mitigated by adjustment of the laser power and pulse density.

10 Mechanical testing results for the effect of laser power on the single layer of material 3, showing the force to break at different laser power levels:

<table>
<thead>
<tr>
<th>Power (W)</th>
<th>Average force to break (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parent</td>
<td>&gt;500N</td>
</tr>
<tr>
<td>30</td>
<td>100</td>
</tr>
<tr>
<td>40</td>
<td>129</td>
</tr>
<tr>
<td>50</td>
<td>146</td>
</tr>
<tr>
<td>60</td>
<td>134</td>
</tr>
</tbody>
</table>

Mechanical testing results for the effect of laser pulse length on fabric force to break:

<table>
<thead>
<tr>
<th>Length of pulse (ms)</th>
<th>Average force to break (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>478</td>
</tr>
<tr>
<td>50</td>
<td>269</td>
</tr>
<tr>
<td>70</td>
<td>269</td>
</tr>
</tbody>
</table>
Microscopic examination showed that fibres were compacted together as a result of exposure to the laser and this effect increased with laser power. Thinning of the fabric is also shown to increase with laser power. Separation between fibres is greater at lower power settings. Progressive thinning of the fabric and compaction of the fibres within the fabric in response to increasing laser power is apparent.

Tests to verify the properties of the use of patterning and workpiece orientation were carried out on material 3. A series of curved wavy lines were applied to the surface of the sample with amplitude of approximately 75mm and repetition every 150mm. The lines were 10mm apart at the apex of the curves. Samples for mechanical testing were cut from the three areas across the width of the fabric; each capturing a differently orientated section of the curve. The results of these tests demonstrate a relationship between the amount of melted material and the effect on elastic behaviour. The orientation of the melted surface pattern has a significant effect on the elastic behaviour of the fabric. Melt lines orientated more steeply from the line of force were located at the outer edges of the curved part of the wavy pattern. Samples cut from the outer edges of the curved parts (orientated at roughly 45 degrees to the line of force) demonstrated reduced extension and increased force compared with the middle section of the curved parts, where the melt lines were orientated less sharply away from (approximately perpendicular to) the line of force.

Mechanical testing results for different surface pattern orientations:

<table>
<thead>
<tr>
<th>Weld orientation</th>
<th>Force at 40% Extension (N)</th>
<th>Extension at 36N (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outer edge of curve (right)</td>
<td>4.4</td>
<td>73.5</td>
</tr>
<tr>
<td>Outer edge of curve (left)</td>
<td>4.1</td>
<td>75.3</td>
</tr>
<tr>
<td>Middle curve</td>
<td>2.6</td>
<td>92.1</td>
</tr>
</tbody>
</table>

It was found that the orientation of the melt pattern in relation to the line of force had a direct effect on the elastic behaviour of the fabric, with steeper orientated melt lines away from the line of force causing fabric extension to decrease and the force required to extend the fabric to increase. Melt patterns that are
orientated less sharply away from the line of force have less of a severe effect on the elastic behaviour of the fabric.

Swimsuits were treated in accordance with the invention by laser treating them with an array of spots using a laser power of 50W, a 2x2mm beam width and a process speed of 5m/min, using material number 2 in the areas partially illustrated in Figure 4. Variable compression was engineered in targeted locations, in this case on the chest, abdomen and front and back of legs and buttocks.

3D body scanning and pressure testing were used to measure the compressive effect of the fabric on the body. In this case, five body measurements are key in relation to the placement of laser-melted zones on the surface of the swimsuit. These are defined as: "waist girth", "girth at crotch height +10cm", "thigh crotch - 4cm left", "thigh crotch -4cm right" and "chest girth". For each of these measurements a comparison was drawn between an unprocessed swimsuit and the laser melt-patterned suit tested. Results showed that for each of these body areas there was a reduction in measured dimensions for a user wearing the swimsuit treated in accordance with the present invention when compared to the plain, untreated swimsuit. The biggest difference of 1cm was recorded for both thighs and girth at crotch height +10cm. A visible difference to the shape of body can also be seen in 3D images generated by the 3D scanner software ('Size Stream' 3D Body Scanner, by Size Stream LLC). A flattening effect to the breasts and abdomen can be clearly seen when comparing the individual shown plain-suited in Figure 5a, and in a swimsuit treated according to the invention in Figure 5b.

<table>
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<th>Area of measurement</th>
<th>Plain suit (cm)</th>
<th>Patterned suit (cm)</th>
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<tr>
<td>Waist girth</td>
<td>76.9</td>
<td>76.5</td>
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<td>Girth at crotch height + 10cm</td>
<td>104.4</td>
<td>103.4</td>
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<tr>
<td>Thigh crotch - 4cm left</td>
<td>59.6</td>
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<tr>
<td>Thigh crotch - 4cm right</td>
<td>60.5</td>
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</tr>
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</table>
A commercially available pressure measurement system ('Picopress', Microlab Elettronica sas, Italy) was used to measure the levels of compression provided by different parts of the swimsuit. The system consists of a hand-held device with a small inflatable bladder attached. The bladder is positioned between the skin and the fabric and is inflated once in position. A pressure measurement in mm Hg is displayed on the monitor of the device. Pressure measurements were taken for each area of the body covered by the laser-melted pattern. The same areas were tested using the plain unprocessed swimsuit to provide a comparison.

Results shown in the table below reveal that the pressure exerted on the body for all areas tested increased with patterning provided according to the invention. For all areas tested the pressure exerted on the body increased by approximately 60% as a result of the laser-treated surface on the fabric.

Comparison of pressure exerted by fabric for plain and laser-patterned swimsuits:

<table>
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<tr>
<th>Part of body</th>
<th>Plain suit (mm Hg)</th>
<th>Patterned suit (mm Hg)</th>
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<tr>
<td>Left thigh</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>Right thigh</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>Left chest</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>Right chest</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>Left buttock</td>
<td>4</td>
<td>7</td>
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<td>Right buttock</td>
<td>4</td>
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<tr>
<td>Waist</td>
<td>3</td>
<td>5</td>
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The above results demonstrate that laser melted patterns according to the invention have a dramatic effect on the elastic behaviour of stretch fabrics and potentially can be used to improve drag resistance and athletic performance through modification of elastic modulus, as well as imparting a unique aesthetic quality unlike any other commercially available technology.
Polymer fibres are, through their manufacture, made from highly crystalline material (65-85% crystalline) and have highly anisotropic properties when the crystalline regions are aligned axially in the fibre making process. The elastic modulus may be 50 times greater in the axial direction for polyethylene (70GPa) than in the transverse direction or similarly in the bulk non-aligned material. Nylon shows similar characteristics, if not so enhanced (1.5GPa in bulk material and 7GPa axial elastic modulus in fibre form). There is also a significant effect on the tensile strength. The tensile strength (axial) of a nylon fibre is 600MPa, whereas bulk non-aligned nylon has a strength of 63MPa. This explains the reduction in strength upon melting a synthetic fabric, as shown in the above results, and also suggests that for retention of strength the fabric should not be melted through its full thickness.

However, the prior-art does not explain the surprising variation in elastic modulus of the fabric upon surface melting, which, without being tied to theory, appears predominantly to be due to limiting the movement of the fibres in the knitted or woven structure when they become locked by the melting process. The invention allows the elastic modulus of the fabric to be controlled in a reproducible way by varying the laser processing conditions. A higher applied energy per unit area results in greater melt depths on the fabric and increased stiffness. Also, if a higher proportion of the fabric area is treated, the elastic modulus of the fabric as a whole is increased.

Apart from the clear benefit provided by the invention when applied to sporting apparel, there are many additional applications in custom-fit and medical garments, such as compression stockings, orthopaedic braces, fashion apparel, underwear, home furnishings. Apart from those already described, other items of sporting apparel include ski and cycle wear with reduced drag, where the surface effects provided by the invention can be used to selectively alter wind resistance.
CLAIMS

1. A method for selectively modifying an elastic modulus of a process region of a textile substrate, comprising exposing with a power beam a plurality of sub-regions, within the process region of the substrate, so as to cause melting and coalescence of the textile fibres within each sub-region, such that at least one elastic modulus of the textile within the process region is modified with respect to the said at least one elastic modulus of the process region prior to the exposure of the sub-regions to the power beam, and wherein the modification of the at least one elastic modulus is dependent upon the combined effect of the exposure of the plurality of sub-regions to the power beam, wherein the textile substrate comprises an elastic fibre content.

2. A method according to claim 1, wherein the elastic modulus is one or more of Young's modulus, shear modulus or bulk modulus.

3. A method according to any of the preceding claims wherein the elastic modulus is measured using a coupon of the textile substrate, the coupon having a size and orientation relative to the sub-regions such that the measured elastic modulus is representative of the elastic modulus of the process region.

4. A method according to claim 3, wherein the coupon contains a plurality of the sub-regions and wherein the volume of each sub-region is less than 20% of the volume of the coupon.

5. A method according to any of the preceding claims where in the power beam is a laser beam.

6. A method according to claim 5, wherein the laser beam is formed from electromagnetic radiation having a principal wavelength within the range 800 to 11000 nanometres.

7. A method according to any of the preceding claims, wherein the power beam density is greater than 1 W mm\(^2\).

8. A method according to any of the preceding claims, wherein the textile substrate is formed from fibres comprising a polymer material.

9. A method according to any of the preceding claims, wherein the power beam and the material of the fibres are selected such that at least 80% of the energy of the power beam is absorbed by the fibres.
10. A method according to any of the preceding claims wherein the melted and coalesced fibres of the sub-regions comprise a total area density in the range 7-80% of the total area of the region.

11. A method according to any of the preceding claims wherein the sub-regions are provided as a pattern within the process region of the substrate.

12. A method according to claim 11, wherein the sub-regions are distributed across the region of the substrate in a regular pattern.

13. A method according to claim 11 or claim 12, wherein some or each of the sub-regions take the form of spots.

14. A method according to claim 13, wherein some or each of the sub-regions in the form of spots are circular, elongate, cross-shaped, V-shaped, ring-shaped and/or open circles.

15. A method according to any of the preceding claims, wherein some or each of the sub-regions have a minimum dimension at least of 0.1 mm.

16. A method according to any of the preceding claims, wherein some or each of the sub-regions have a dimension in the range 0.1 to 20 mm.

17. A method according to claim 16, wherein some or each of the sub-regions have a dimension in the range 1 to 4 mm.

18. A method according to any of the preceding claims wherein the substrate in a sub-region has a thickness and wherein the power beam causes only part of the material to be melted within the sub-region within the through-thickness direction.

19. A method according to any of the preceding claims, wherein the power beam is applied to sub-regions within the process region upon each side of the textile substrate.

20. A method according to any of the preceding claims, wherein the textile substrate is formed from the plurality of layers and wherein the exposure to the power beam causes the fusing of at least two of the layers in the sub-regions.

21. A method according to any of the preceding claims, wherein the textile substrate is provided with a power beam transparent cover layer through which the sub-regions are exposed to the power beam.
22. A method of creating a modified textile substrate for use in a garment, comprising:
   a) Identifying a process region of a textile substrate of a garment in which the elastic modulus of the textile is to be modified;
   b) Selecting one or more modification parameters defining the intended modification to the elastic modulus in the process region;
   c) Selecting a set of process parameters suitable to effect the defined modification according to the selected modification parameters; and
   d) Using a method according to any of the preceding claims, according to the selected process parameters to effect the modification of the textile substrate in the process region.

23. A method according to claim 22, wherein one or each of step (a), step (b) or step (c) are performed by the use of a computer model of the mechanical behaviour of the garment.

24. A method according to claim 22 or claim 23, further comprising:
   (e) forming a garment using the processed textile substrate in which the elastic modulus of the process region has been modified.

25. A method according to any of the preceding claims, wherein the elastic fibre content comprises an elastomer.

26. A method according to any of the preceding claims, the elastic fibre content comprises one or more of polyurethane, elastane, polychloroprene, neoprene or rubber.

27. A method according to any of the preceding claims, wherein the power beam has a beam width of between 0.1 mm and 20 mm, more preferably between 1 mm and 4 mm.

28. A method according to any of the preceding claims, wherein the power beam has a circular beam cross section.

29. A method according to any of the preceding claims, wherein exposing with a power beam a plurality of sub-regions within the process region of the substrate comprises controlling the power beam such that the elastic fibre content does not melt and the melted and coalesced fibres surrounding the elastic fibres restrict their movement.

30. A textile modification system for selectively modifying an elastic modulus of a process region of a textile substrate, the system comprising:
a support against which the textile substrate is located when in use; power beam emission apparatus arranged to direct a power beam on to a process region of the textile substrate located against the support, wherein the power beam emission apparatus and the support are arranged to be relatively moveable such that the power beam may expose a number of sub-regions within the process region; and a control system adapted to expose to a power beam of the power beam emission apparatus a plurality of sub-regions, within the process region of the substrate, so as to cause melting and coalescence of the textile fibres within each sub-region, such that at least one elastic modulus of the textile within the process region is modified with respect to the said at least one elastic modulus of the process region prior to the exposure of the sub-regions to the power beam, and wherein the modification of the at least one elastic modulus is dependent upon the combined effect of the exposure of the plurality of sub-regions to the power beam.

31. A textile modification system according to claim 30, wherein the power beam emission apparatus is a laser.

32. A textile modification system according to claim 30 or claim 31, further comprising a clamp for urging the textile substrate against the support.

33. A textile modification system according to any of claims 30 to 32, further comprising a power beam transparent sheet adapted to be urged against the surface of the textile substrate such that the power beam passes through the transparent sheet and is incident upon the surface of the textile substrate.
Fig. 2

100 Analyse suitability of textile

110 Select region(s) for modification

120 Select modification parameters

130 Select process parameters

140 Arrange textile on surface

150 Pre-treat with absorber (optional)

160 Apply transparent sheet (optional)

170 Apply laser to sub-regions

180 Remove textile substrate

190 Further processes
**INTERNATIONAL SEARCH REPORT**

**International application No**

PCT/GB2017/05Q919

**A. CLASSIFICATION OF SUBJECT MATTER**

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According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

D06Q  D06M  D06C  A41D  A61F  B23K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

<table>
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<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
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<td>US 4589 884 A (GI LPATRICK MICHAEL W [US])</td>
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<td>&amp; JP 2008 291397 A (KURARAY TRADING KK)</td>
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**Further documents are listed in the continuation of Box C.**

**See patent family annex.**

* Special categories of cited documents:
- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier application or patent but published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed

**Date of the actual completion of the international search**

4 May 2017

**Date of mailing of the international search report**

16/05/2017

Name and mailing address of the ISA:

European Patent Office, P.B. 5818 Patentlaan 2

NL - 2280 HV Rijswijk

Tel. (+31-70) 340-2040,

Fax: (+31-70) 340-3016

Authorized officer

Barathe, Rainer

Form PCT/ISA/210 (second sheet) (April 2005)
<table>
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<td>Y</td>
<td>W0 97/16279 A1 (TECHNOLINES INC [US]) 9 May 1997 (1997-05-09) figures 1, 38-43</td>
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<td>JP 2004 156199 A (WACOAL CORP) 3 June 2004 (2004-06-03) abstract; figures 1-122</td>
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This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. **X** Claims Nos.: 22-29
   because they relate to subject matter not required to be searched by this Authority, namely:
   see FURTHER INFORMATION sheet PCT/ISA/210

2. **☐** Claims Nos.:  
   because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. **☐** Claims Nos.:  
   because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

This International Searching Authority found multiple inventions in this international application, as follows:

1. **☐** All required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. **☐** As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. **☐** As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:  

4. **☐** No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:  

**Remark on Protest**  
- The additional search fees were accompanied by the applicant’s protest and, where applicable, the payment of a protest fee.
- The additional search fees were accompanied by the applicant’s protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- No protest accompanied the payment of additional search fees.
Continuation of Box II.1

Claims Nos.: 22-29

1) The steps b), c) and d) of claim 22 are so vague and unclear (see paragraph 2 below) that they are considered as an attempt to define a mental act. Scheme, rules and method for performing mental acts are excluded from patentability (Rule 39.1(iii) PCT). This objection applies also to claims 23-29, all depending on claim 22. 2) Claim 22 does not meet the requirements of Article 6 PCT because the matter for which protection is sought is not clearly defined. The claim attempts to define the subject-matter in terms of the result to be achieved, which merely amounts to a statement of the underlying problem and because the technical steps necessary for achieving this result and the features involved are vague as shown by the following sentences: - "selecting one or more modifications on parameters defining the intended modification"; - "selecting a set of process parameters suitable to effect the defined modification on according to the selected modification parameters" and - "using a method, according to the selected process parameters, to effect the modification on. 3) Basically, claim 23 makes reference to a computer model. The word "model" is synonym of program and computer programs are excluded from patentability (Rule 39.1(vi) PCT). This objection applies also to claims 24-29, all dependent on claim 23.
<table>
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<th>Publication date</th>
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