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(71) Applicant *(for all designated States except US)*: **UNIVERSITY OF LEEDS** [GB/GB]; Leeds, West Yorkshire LS2 9JT (GB).

(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: **MAO, Ningtao** [GB/GB]; School of Design, University of Leeds, Leeds West Yorkshire LS2 9JT (GB). **TAYLOR, Mark** [GB/GB]; School of Design, University of Leeds, Leeds West Yorkshire LS2 9JT (GB).

(74) Agent: **HARRISON GODDARD FOOTE**; Saviour House, 9 St Saviourgate, York, Yorkshire YO1 8NQ (GB).

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(54) Title: EVALUATION APPARATUS AND METHOD

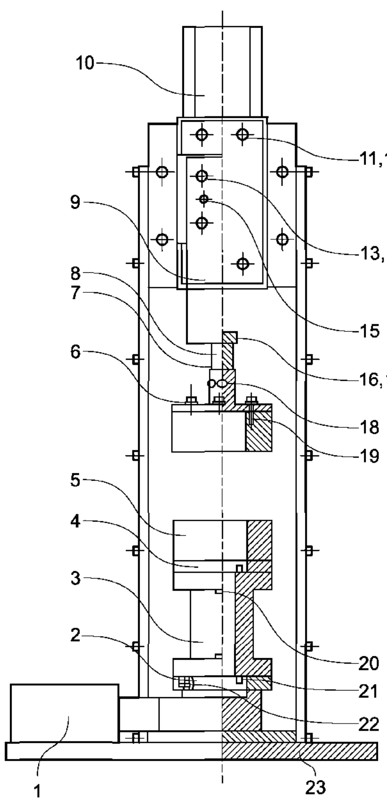

FIG. 2A

(57) Abstract: The invention provides an apparatus and methods which are capable of providing a quantitative measure of fabric handle, softness of a sheet material, or means of discriminating between such materials by successfully mimicking the actions of individuals in the fabric hand or softness evaluation process, and which is able to provide mechanical response signals which provide a measure of the physical reaction of the fabric or sheet material to forced mechanical deformation. The apparatus according to the invention comprises: (a) a linear displacement device; (b) a rotary stage; (c) at least one sample holder; (d) a load cell; (e) at least one pressure sensor; (f) a torque sensor; and (g) a support frame. The methods of the invention involve subjecting a fabric or sheet material sample to at least one of six modes of deformation process, selected from pure twisting, pure stretching, pure compression, stretch-twisting, compression-twisting and friction and determining fabric handle indices from the derived data.

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EVALUATION APPARATUS AND METHOD

Field of the Invention

[0001] This invention relates to an apparatus and method for the evaluation of the properties of fabrics and materials, most particularly textile fabrics. More specifically, it provides a system which facilitates the determination of fabric handle in a manner that mimics the perception of comfort made by individuals. It also provides a means for the determination of the softness of sheet materials and discrimination between such materials.

Background to the Invention

[0002] Fabric hand – otherwise known as fabric tactile comfort – is a critical quality parameter in the assessment of fabric aesthetics and relates to the essentially subjective perception of clothing comfort made by an individual. It is one of the key factors used by consumers in the subjective selection of textile products. Fabric handle, however, provides an objective assessment of fabric properties during various physical deformations of fabric materials. Both fabric hand and fabric handle provide textile designers, retailers and developers with a quantitative measure by means of which the level of fabric comfort and customer acceptance at the point of sale can be predicted. However, the existing benchmark methods for the objective assessment of both fabric hand and fabric handle are complicated and controversial and, therefore, have serious drawbacks. Typically, hardly any of existing objective fabric hand/handle evaluation systems include the evaluation of the recovery of fabric deformation, including either self-recovery of fabric deformation by its own elastic forces or forced recovery of fabric deformation by external forces. By way of contrast, the evaluation of such recovery of fabric deformation is the norm for subjective fabric hand evaluation processes.

[0003] In addition, the interpretation of results from these existing systems requires specialist expertise in both fabric technology and the testing system and, as a consequence, the application of the systems is largely restricted to the purposes of scientific research, rather than finding potentially much wider application in the areas of commercial textiles and consumer product industries.

[0004] The first commercial attempt to objectively measure fabric hand/handle was undertaken by Pierce in the 1930s. Subsequently, in the 1970s, researchers from Japan and Australia developed two systems, known as the KES-F and FAST systems, for measuring individual fabric properties, and then constructed models of the relationship between fabric properties – such as bending rigidity, shearing stiffness, friction, and the like – and subjective hand evaluation values for objectively evaluating fabric hand. However, in addition to the drawbacks previously mentioned, these systems were found to be complicated and expensive. Moreover, the fabric deformation behaviour occurring in such systems did not replicate the fabric deformation observed in subjective fabric hand evaluation, and the relationship between the subjective fabric hand value and the measured fabric properties was based on limited experimentation and was arbitrary. These systems, therefore, lacked an objective indices system to discriminate between fabrics, and they also required expert knowledge in order to meaningfully interpret the results.

[0005] The evaluation of the handle of fabrics and softness of other materials, such as polymeric film, by using nozzle extraction methodology, or similar techniques relying on the use of apertures, openings, slits, etc., has been variously reported in US-A-2718142, US-A-2786352, US-A-4103550 and WO-A-2006/014870. A similar method is also adopted in US-A-6860148 for high throughput screening of the fabric handle of a plurality of fabric materials.

[0006] Various other instruments have also been developed, such as the PhabrOmeter, which measures fabric deformation and frictional responses when acting on the fabric with a metal ring/nozzle, a group of metal rods or a rubber finger. Again, however, none of these systems proved to be simple to use, and all required expert operators for interpretation of the results, thereby seriously limiting their application.

[0007] Further alternative methods for the measurement of the softness or tactile properties of fabrics and other materials have also been reported. Thus, the evaluation of fabric softness through the measurement of resistance to penetration by sharp pins is documented in US-A-3541843, whilst US-A-3683681 discloses the assessment of paper fabric softness by detecting and indicating sound level frequencies which are related to fabric properties. A method of directing ultrasonic energy towards paper and then determining the magnitude of the portion of reflected energy is reported in US-A-4548081 as a means of determining softness, and US-A-4869101 and US-A-4980646 each describe the measurement of the softness of a fibrous product by respectively using a piezoelectric polymer film sensor and an impedance tomographic tactile sensor. In addition, US-A-6397672 teaches a method for determining the frictional properties of materials.

[0008] Again, however, none of these techniques facilitates the determination of fabric hand, or fabric handle, in a simple, repeatable, economically attractive and reliable manner, since each suffers from the drawback of expense or technical complexity, requiring specialist technical expertise relating to the system and fabric technology in order to provide meaningful results.

[0009] Previous research[1] has also shown that the characteristics of the compression buckling of different sheet materials were distinctively different; examples of the buckling curves and cyclic buckling, and the recovery behaviour, of a series of fabrics including some common sheet materials has been reported by Lindberg *et al*[1].

[0010] While fabric buckling or fabric buckling wrinkle is one of the deformation parameters in apparel fabrics and was found[1] to be possibly related to the fabric handle, there is no system available to characterise fabric handle by utilising fabric buckling deformation behaviour. It was shown[2,3,4,5,6,7,8] that the fabric plate compression buckling was related to fabric stiffness. Fabric buckling wrinkle of knitted and woven fabric buckling wrinkles were also investigated[9,10], and the width the buckling wrinkle patterns in the circumference directions in a fabric shell compression buckling were given[11] in a semi-empirical equation as follows:

$$w = 3.38\sqrt[4]{\frac{E_1}{E_2}}\sqrt{Rt}$$

where E_1 and E_2 are the Young's modulus of the fabric in the axial and circumferential directions of the fabric shell respectively, R is the radius of the cylindrical fabric shell and t is the fabric thickness.

[0011] Lindberg *et al*[1,12] investigated the characteristics of plate and shell compression buckling of various fabrics and defined the fabric formability in garment technology. These workers defined the critical fabric buckling load for the buckling of a fabric plate, P_{CR} by using Euler's equation for buckling of a bar as follows[1,12]:

$$P_{CR} = \frac{4\pi^2 EI}{L^2}$$

where E is the modulus of elasticity of the fabric plate, L is the length of the fabric plate subjected to buckling deformation and I is the moment of inertia based on the geometrical dimensions of the fabric and is given by the equation[1,12]:

$$I = \frac{Lt^2}{12}$$

where L and t are the length and thickness of the fabric plate, respectively.

[0012] Although fabric compression buckling is found[1] to be related to the fabric bending stiffness and fabric torsion buckling is directly dependent on the fabric shear modulus, there is little research on the relationship between fabric torsion buckling behaviour and either fabric hand or fabric handle. Consequently, in the light of all the previous research, there is an evident requirement for a simple inexpensive system which can be readily applied to the determination of fabric hand or fabric handle and which can thereby find wide commercial applicability.

Summary of the Invention

[0013] The present inventors have therefore sought to provide a system which is capable of providing a quantitative measure of fabric handle, firstly by successfully mimicking the three major deformations of a fabric in the fabric hand evaluation process as carried out by human hand, specifically by human experts – these deformations being compression buckling, torsion buckling and friction deformation – and which is then able to provide mechanical response signals which provide a measure of the physical reaction of the fabric to such forced mechanical deformation.

[0014] Thus, according to a first aspect of the present invention, there is provided an apparatus for the determination of fabric handle and softness of sheet materials, said apparatus comprising:

(a) a linear displacement device;

(b) a rotary stage;

(c) at least one sample holder;

(d) a load cell;

(e) at least one pressure sensor;

(f) a torque sensor; and

(g) a support frame.

[0015] In typical embodiments of the invention, said load cell is attached to said linear displacement device which is fixedly attached, directly or indirectly, to said support frame. In typical embodiments of the invention, said rotary stage is fixedly attached to a support base which is fixedly attached to said support frame. Said torque sensor is typically attached to said rotary stage. Most generally, said rotary stage and said linear displacement device are linearly spaced apart within said support frame.

[0016] In embodiments of the invention, at least one sample holder is fixedly or removably, directly or indirectly, attached to said linear displacement device. In further embodiments of the invention, at least one sample holder is fixedly or removably, directly or indirectly, attached to said rotary stage. Typically, a sample holder is attached to each of said linear displacement device and said rotary stage. Typically, a first sample holder is indirectly attached to said linear displacement device via said load cell and a second sample holder is indirectly attached to said rotary stage via said torque sensor.

[0017] Said at least one pressure sensor is typically comprised in said at least one sample holder. Different embodiments of the invention envisage the use of sample holders comprising a multiplicity of pressure sensors, a single pressure sensor or no pressure sensor. Accordingly, in embodiments of the invention wherein a sample holder is attached to each of said linear displacement device and said rotary stage, said at least one pressure sensor may be located in either or both of said sample holder associated with said linear displacement device or said sample holder associated with said rotary stage.

[0018] Attachment of the components of the apparatus to one another may conveniently be achieved by the use of a plurality of suitable fixing components including, for example, connecting members, bolts, screws, locking members and gaskets.

[0019] Said apparatus may be applied to the determination of the fabric handle of any textile fabric material. In addition, it may be used to discriminate between a wide range of sheet materials including, for example, sheets of paper, tissue, film, foam, mesh, non-woven material, gel, skin, leather, metal foil, composite, or similar material. In the interests of brevity, reference is hereinafter made to the determination of fabric handle, but such references may equally be understood to refer to discrimination between any of a wide range of sheet materials, including those detailed above.

[0020] Typically, the at least one sample holder comprises at least one cylindrical sample holder. In embodiments of the invention, the sample holders comprise clamping devices. In preferred embodiments of the invention, the at least one sample holder comprises a pair of cylindrical sample holders comprising sample clamps which are adapted to hold a sample of fabric.

[0021] The sample holders and/or their surfaces may be comprised of any of a number of suitable materials selected from, but not limited to, wood, glass, ceramic materials, metals, metal oxides, polymeric materials, silicone gels or rubbers, natural and artificial rubbers, textile fabrics, which may optionally comprise the material under test. Suitable polymers may, for example, include polyamides (e.g. nylons), polyesters, polyalkenes (e.g. polyethylene or polypropylene), PTFE, polyacrylics, polyarylenes (e.g. polystyrene), or copolymers thereof.

[0022] The sample holders and their surfaces may optionally comprise a composite surface structure incorporating at least one sensory device, typically multiple sensors or arrays of sensors (for example, a haptic sensory system) facilitating measurement of frictional and pressure forces (and/or their distribution) and deformation which occurs during the course of the friction measurements.

[0023] The linear displacement device preferably comprises a computer controlled linear displacement device, and is adapted so as to facilitate linear stretching and compression of a sample of fabric in the linear direction of the fabric, optionally on a cyclical basis, whilst the rotary stage, which is preferably computer controlled, facilitates twisting of the fabric in the radial direction in both clockwise and anti-clockwise directions, or cyclically in both directions. Measurement of the force during the linear stretch/compression deformation of the fabric is achieved via the load cell, whilst the corresponding torque/angular momentum required to deform the fabric sample radially is determined by means of the torque sensor. In this way, a combination of stretch, compression and twisting, cyclically if necessary, may be performed in order to characterise the fabric softness.

[0024] The Young's modulus of the fabric compression during fabric initial compression prior to fabric compression buckling can be approximately obtained by using Euler's equation for elastic shell theory as follows:

$$E = \frac{FL}{\Delta L \pi (R_0^2 - R_1^2)}$$

wherein E is the elastic modulus, ΔL is the displacement of the fabric of initial length L, F is the applied force and R_0 and R_1 are the outer and inner radius of the fabric cylindrical shell, respectively, wherein $R_0 = R_1 + t$, where t is the fabric thickness.

[0025] Similarly, the Young's modulus of the fabric torsion during fabric torsion deformation prior to fabric torsion buckling can be approximately obtained by using Euler's equation for elastic shell theory as follows:

$$G = \frac{32TL}{(R_0^4 - R_1^4)\pi\phi}$$

in which G is the shear modulus of elasticity (N/m^2), T is the torque applied (Nm), Φ is the total angle of the twist (radians) and L, R_0 and R_1 are the initial length (m), and the outer and inner radius (m) respectively, of the fabric cylindrical shell, as previously defined.

[0026] The torsional stiffness (J) (or the polar moment of inertia of the cross-section) and the torsional rigidity (GJ) of the thin cylindrical fabric shell are defined as follows:

$$J = \frac{\pi}{32}(R_0^4 - R_1^4) \quad (m^4)$$

$$GJ = \frac{TL}{\phi} \quad \text{(Nm}^2\text{)}$$

[0027] Thus the Poisson's ratio of the fabric, ν, can be calculated by using the equation below

$$\nu = 1 - \frac{2G}{E}$$

wherein G and E are as previously defined.

[0028] While a series of indices based on the fabric compression buckling behaviour were identified by Lindberg *et al*[1], these indices can now be obtained during testing and subsequently linked with fabric handle and fabric softness.

[0029] Furthermore, based on the buckling curves of the fabric in stretch, compression, and torsion deformation, and the buckling curves of the various above buckling combinations, and the cyclic buckling behaviour of the fabric, additional indices can be obtained and linked with fabric softness and handle. Examples of such indices include the critical buckling force, the recovery energy and the differences of critical buckling force, and these can be obtained from both the measured curves and the post buckling equations. Thus, for example, the lower critical buckling force can be obtained from the post buckling curves[13] and the upper critical buckling force (or theoretical critical buckling force) in compression is determined as follows[13]:

$$P_{cr} = \frac{2\pi E}{[3(1-\nu^2)]^{1/2}} t^2$$

wherein E, ν and t are as previously defined.

[0030] The upper critical buckling force (or theoretical critical buckling force) in torsion deformation is defined by the following equation[13]:

$$P_{cr} = \frac{0.544\pi E}{(1-\nu^2)^{3/4}} R^{-\frac{1}{2}} t^{\frac{5}{2}}$$

in which $R = R_0 - t/2$ and E, ν and t are as previously defined. Also, the coefficients of extensional stiffness parameter, C, defined as:

$$C \equiv \frac{Et}{1-\nu^2},$$

and bending parameter, D, derived from the equation:

$$D \equiv \frac{Et^3}{12(1-\nu^2)},$$

can be obtained and compared with theoretical results. Two other unique indices can be obtained, namely the wave speed of compression buckling, c_1, defined as:

$$c_1 = \sqrt{C/\rho t}\,,$$

wherein C is the coefficient of extensional stiffness parameter defined above, and ρ and t are the fabric bulky density and fabric thickness, respectively, and the wave speed of torsion buckling, c_2, derived from:

$$c_2 = \sqrt{E/[2\rho(1+\nu)]}\sqrt{1+(t/R)^2/12}\,,$$

in which E, ρ, ν and R have their previously ascribed meanings.

[0031] During operation of the apparatus according to the first aspect of the invention, the cylindrical shell fabric sample is attached onto the smooth surface of a metal cylinder sample holder by frictional force through a pressure force perpendicular to the fabric plane. When the drag force is equal to the friction force during the extension of the fabric sample, the friction coefficient of the fabric against the smooth metal surface is measured when there is a steady relative movement between the cylindrical fabric sample on the surface of the metal cylinder sample holder (illustrated in Figures 2(b) and 3). The drag force, F, is obtained from the loadcell, whilst the pressure force exerted perpendicular to the fabric surface is measured by the pressure sensor. Thus, the friction coefficient, μ, can be obtained as follows:

$$\mu = \frac{F}{N}$$

wherein N is the pressure force applied perpendicular to the fabric surface.

[0032] Thus, according to a second aspect of the invention, there is provided a method for the determination of fabric handle or softness of sheet material, said method comprising the steps of:

(a) providing an apparatus according to the first aspect of the invention;

(b) attaching a fabric or sheet material sample to said apparatus by means of said at least one sample holder;

(c) applying at least one of:

(i) a linear stretching force and/or a linear compression force by means of said linear displacement device; and

(ii) a radial twisting force and/or torque by means of said rotary stage;

(d) determining the magnitude of the linear stretching force and/or linear compression force by means of said load cell;

(e) determining the magnitude of the radial twisting force and/or torque by means of said torque sensor; and

(f) determining the response of the fabric to the physical deformation resulting from the application of said one or more forces and/or torque.

[0033] Said application of forces to said fabric or sheet material may be carried out so as to continuously deform the fabric or sheet material. Alternatively, said application of forces to said fabric or sheet material is carried out cyclically in order to repeatedly deform the fabric or sheet material in a programmable deformation velocity and deformation length. In this way, and by variation of the nature of the forces which are applied to the fabric or sheet material, the apparatus and method of the invention may be utilised in order to provide any of a stretch and compression measuring system, a torsion measuring system, and a friction measuring system.

[0034] In operation according to the method of the invention, a fabric sample is typically prepared with exerted bending curvature, for example in one or more essentially cylindrical tube shapes, which may either be open or closed, and which may be clamped onto a pair of sample holders in order that the linear displacement device can stretch and compress the fabric tube, preferably cyclically, in the direction of the fabric tube, with the stretch/compression force then being measured via the load cell. The dynamic displacement of one end of the fabric sample during the stretch/compression deformation process is either provided by the linear displacement device or is measured by another sensor. The rotary stage is able to twist the fabric tube in the radial direction, both clockwise and anticlockwise, and preferably cyclically in both directions, with the corresponding torque/angular momentum required to deform the fabric sample being determined via the torque sensor. The dynamic angular displacement of the fabric sample during the twist deformation process is either provided by the rotary stage or is measured by another sensor.

[0035] As previously noted, fabric hand is a subjective tactile sensory perception of fabric texture, wherein the evaluation of the physiological perception of a fabric is typically performed by means of various physical deformations of the fabric using a human hand, for example by repeated compression/squeezing, extension, twisting, rubbing or other deformation of the fabric. In this evaluation process, different terminologies are used to describe the tactile properties of the fabric, and comparative values are then used to quantify those tactile properties, these values reflecting both the forces applied to the fabric by the hand and whether the fabric is easily deformed (compressed/squeezed, extended, twisted, rubbed, etc.)

[0036] Whilst it would be ideal for fabric hand evaluation if a means could be provided for the objective quantification of the deformation of the fabrics during the subjective fabric hand evaluation process, and if such a means could be applicable in all situations, i.e. valid for all operatives and not subject to individual interpretation, it is not only difficult to establish such a system technically, but it is also difficult to standardise the fabric deformation process between different people. Therefore, it is necessary to adapt the fabric handling system to deform the fabric in a way which mimics fabric deformation in a subjective fabric hand evaluation process (by means of squeezing/compression, extension, twisting, rubbing, etc.) in a standardised and controlled manner. This issue is also addressed by means of the present invention, which provides a method wherein the forces used, and energy consumed in order to deform the fabrics, are measured and used in order to quantify the fabric deformations.

[0037] Thus, according to a further aspect of the present invention, there is provided a method for the determination of fabric handle indices, said method comprising the steps of:

(a) performing the method according to the second aspect of the invention;

(b) determining the indices of fabric sponginess (SP), fabric crispness (CR), fabric flexibility (FL), fabric stiffness (ST) and fabric smoothness (SN) from the measured values obtained; and

(c) calculating the fabric softness index SF = ST + FL.

[0038] According to the present invention, the calculated values of fabric sponginess, fabric crispness, fabric flexibility and fabric stiffness are the average of the values in the weft and warp directions.

Brief Description of the Drawings

[0039] Embodiments of the invention are further described hereinafter with reference to the accompanying drawings, in which:

Figures 1(A-1), 1(A-2). 1(B-1), 1(B-2), 1(C-1), 1(C-2), 1(D-1), 1(D-2), 1(E–1) and 1(E–2) include typical compression buckling curves of three sheet materials according to the method of the invention;

Figure 2(A) is a side elevation of an apparatus according to the invention prior to use according to the method of the invention;

Figure 2(B) is a side view of a removable fabric sample holding system used in the apparatus of the invention according to the method of the invention;

Figures 3(A) and 3(B) are side elevations of a section of the apparatus according to the invention showing different embodiments of the systems used for the measurement of fabric friction coefficients;

Figure 4(A) shows the components of the apparatus according to the invention used in the measurement of fabric surface friction by means of the relative linear movement of a fabric cylindrical shell on the surface of a metal cylinder surface;

Figure 4(B) shows a graphical representation of the fabric surface friction force measured for a fabric surface against an identical fabric surface;

Figures 5(A, 5(B), 5(C), 5(D), 5(E) and 5(F) show graphical representations of the measured torque when fabric samples are twisted clockwise and then anticlockwise according to the method of the invention;

Figures 6(A), 6(B), 6(C) and 6(D) graphically illustrate the definitions of A1, A2, A3, A4, A5 and A_{1CP1} in compression buckling deformation; and

Figures 7(A), 7(B), 7(C) and 7(D) graphically illustrate the definitions of A1, A2, A3, A4, A5 and A_{1CP1} in torsion deformation.

Description of the Invention

[0040] The fabric handle or sheet material softness evaluation system according to the invention is based on the principle that the fabric handle or material softness is quantified by the measurement of the physical reaction of the fabric or material to forced mechanical deformation, including twisting, stretching, compression, relative friction, and combinations thereof. Unlike the systems of the prior art, such as KES-F and FAST, which measure individual mechanical properties of the targeted fabrics, the system according to the invention successfully mimics the actions of human experts in the evaluation process and is able to directly acquire mechanical response signals for the fabric or material sample.

[0041] Thus, the system evaluates handle and softness by assessing the response of a sample which is subjected to such forced mechanical deformation; this is achieved by measurement of the forces – stretch, compression, torque, friction, angular momentum and energy – which are required in order to deform the sample.

[0042] Specifically, fabric handle is evaluated from the response of a fabric sample in the shape of a cylindrical shell under a dynamic mechanical deforming process. The mechanical deformation includes compression, extension, torsion, friction or any combination thereof, and the fabric with bending curvature is preferably in the form of a cylindrical tube, a curved shell or a piece of fabric roll. The fabric sample may be single layered or multilayered.

[0043] The radius of the inner curvature of said fabric sample with exerted bending curvature generally ranges from 0.01 mm to 200 mm, whilst the effective length of the fabric sample under test in the system preferably ranges from 0.01 mm to 400 mm. The ratio of the radius of the inner curvature of the fabric cylinder to its length typically falls in the range of from 0.02 to 100, preferably from 0.2 to 10, more preferably from 0.5 to 2, and most preferably said ratio is 1.

[0044] As noted above, there are three preferred embodiments of the apparatus and method of the present invention, these comprising an extension and compression measuring system, a torsion measuring system and a friction measuring system.

[0045] Thus, in one preferred embodiment of the invention, there is provided a fabric stretch and compression measuring system wherein the computer controlled linear displacing unit, the load cell (tensile and compression) unit, and the fabric sample clamping unit of an apparatus according to the invention are deployed such that the displacing unit moves upwards and downwards linearly so as to exert a tension force/ compression force on the fabric sample fixed by the clamp unit. The magnitude of this force is measured by the load cell when the fabric is stretched/compressed by the computer controlled linear displacing unit.

[0046] In a further preferred embodiment of the invention, there is provided a fabric torsion measuring system wherein the computer controlled rotary displacing unit (rotary stage), the torque sensor (bi-directional) unit, and the fabric sample clamping unit of an apparatus according to the invention are deployed such that the displacing unit rotates at a constant angular speed clockwise and anti-clockwise so as to exert a radial force on the fabric sample fixed by the clamp unit. The torsion force and torque exerted on the fabric sample are measured by the torque sensor when the fabric is twisted in this way by the computer controlled rotary displacing unit.

[0047] Thus, the method of the invention requires the application of at least one force on the fabric sample so as to promote a specific deformation of the fabric. The testing, therefore, is carried out based on one or a combination of the dynamic deformation processes of compression, extension, torsion and friction. Specifically, the invention employs six different modes of deformation process, as follows:

1. Pure Twisting, wherein the fabric sample is deformed by twisting the sample at a given angle, e.g. 10°, 720°, etc.
2. Pure Stretching, wherein the fabric sample is deformed by stretching the sample at a selected displacement or elongation, e.g. 10 mm or 10%.
3. Pure Compression, wherein the fabric sample is deformed by compressing the sample at a selected displacement or compression, e.g. 10 mm or 10%.
4. Stretch-Twisting, wherein the fabric sample is deformed by stretching the sample at a selected displacement or elongation, e.g. 10 mm or 10%, whilst simultaneously deforming the sample by twisting at a given angle, e.g. 10°, 720°, etc.
5. Compression-Twisting, wherein the fabric sample is deformed by compressing the sample at a selected displacement or elongation, e.g. 10 mm or 10%, whilst simultaneously deforming the sample by twisting at a given angle, e.g. 10°, 720°, etc.
6. Friction, wherein a force is exerted so as to pull the metal cylinder sample holder such that it has a relative movement against the cylindrical shell fabric sample, and wherein a pressure sensor with a pre-set pressure is attached to either the cylinder sample holder or the sample clamp in order to measure the pressure exerted on the fabric surface by virtue of its action against the surface of the metal sample holder, such that the friction force may be obtained from the load cell connected with the cylinder sample holder.

Thus, it can be seen that the Stretch-Twisting mode of deformation is essentially a combination of the Pure Stretching and Pure Twisting modes, whilst the Compression-Twisting mode is essentially a combination of the Pure Compression and Pure Twisting modes.

[0048] The mechanical properties of the fabric sample are measured, and the changes in those properties are monitored, during the operation of the method of the invention, thereby facilitating the establishment of the dynamic characteristics of these mechanical properties from an analysis of the results. Measurement of the effects of the above deformation processes on a fabric sample allows for the following properties of the sample to be determined:

(1) Pure Twisting – assessment of torsion force and torque;

(2) Pure Stretching – assessment of stretch force and modulus of the fabric deformation;

(3) Pure Compression – assessment of compression force, the stiffness of the fabric deformation and the number of patterned creases/wrinkles on the fabric surface;

(4) Stretch-Twisting – assessment of torsion force, torque, stretch force and modulus of the fabric deformation;

(5) Compression-Twisting – assessment of torsion force, torque, compression force, and stiffness of the fabric deformation;

(6) Friction – assessment of friction force and friction co-efficient.

[0049] From an evaluation of the data obtained from the apparatus and method of the invention, it is possible to quantify the fabric handle in the following three ways:

- The measured properties (1)-(6) detailed above;
- Analysis of the characteristics of the dynamic changes of the measured mechanical properties of the fabric sample during the deformation, optionally cyclic, processes e.g. Pure Stretching, Compression-Twisting, etc;
- Characterisation of the measured mechanical properties of the fabric sample based on theoretical models of the fabric deformation in the detailed testing processes.

[0050] In addition, the present invention also provides for the assessment of fabric handle in terms of the indices previously mentioned. In principle, the deformation of fabrics in both macrostructure and microstructure in subjective fabric hand, as well as objective fabric handle, evaluation processes can be divided into three types: self-recoverable deformation, recoverable deformation and unrecoverable deformation.

[0051] The elastic deformation in fabric materials and structures is self-recoverable after the external force (e.g. elastic elongation, elastic compression, elastic torsion deformation, etc.) is withdrawn. The work done by the elastic force to recover this elastic deformation in the fabric handling process reflects the spongy feeling of the fabric on the human hand in subjective fabric hand evaluation processes.

[0052] The recoverable deformation in fabric materials and structures can be recovered when an external force is applied (e.g. relative movement and shape changes of yarns/filaments in fabrics, relative movements and shape changes of fibres in yarns, and changes in elongation, compression and torsion). The energy consumed both to achieve and to recover this type of deformation in the fabric handling process is usually used to overcome the friction force encountered, and it represents how easily the fabric is deformed and the deformation is recovered. In other words, it reflects how flexible the fabric feels to the hand in subjective fabric hand evaluation tests.

[0053] The unrecoverable deformation usually represents the permanent damage in either fabric materials or structures which is not recoverable by any means (e.g. cracks/elongation in fibres and creases/wrinkles in the fabric surface). The energy consumed in this type of deformation in objective fabric handling processes is related to how easily the creases or wrinkles are formed in a fabric, and is similar to crispy feeling in subjective fabric hand evaluation.

[0054] In addition to these three types of fabric deformation, the present inventors have established that both the average force and the total energy used to deform a fabric are closely linked with the stiff feeling of a fabric on the human hand.

[0055] Thus, on the basis of the fundamental analysis previously discussed and the analysis of the experimental results of fabric handle evaluation by means of the present invention, there has been established a system of measured values obtained according to the invention which corresponds to four primary indices of the fabric hand sensory feeling as follows:

- The fabric stiffness in subjective fabric hand evaluation corresponds to the total energy consumed to achieve the whole fabric deformation, which is proportional to the force used to deform the fabric (but exclude the energy consumed in recovering the fabric deformation);
- The fabric sponginess in subjective fabric hand evaluation corresponds to the work done by elastic forces in recovering self-recoverable deformation;
- The fabric crispiness in subjective fabric hand evaluation corresponds to the energy consumed to achieve unrecoverable fabric deformation;
- The fabric flexibility in subjective fabric hand evaluation corresponds to the energy consumed both to achieve and to recover recoverable fabric deformation; and

- The fabric smoothness in subjective fabric hand evaluation corresponds to the frictional coefficient during fabric-to-fabric self-friction.

[0056] In summary, therefore, human hand sensory feelings towards different fabrics in fabric hand evaluation can be represented by a combination of the fabric friction properties and the amount of the four types of energy detailed above which is consumed in fabric handling tests according to the invention.

[0057] From the above discussion, it may be concluded that fabric sponginess, fabric flexibility, fabric crispiness and fabric smoothness are all independent of each other.

[0058] While the fabric stands tensile and compression stress and strain during its buckling deformation in compression processes, it has pure shear stress and strain in the fabric torsion deformation in the twisting process. Consequently, the fabric stiffness, fabric sponginess, fabric crispiness and fabric flexibility in both compression and shear deformation are defined according to the following considerations.

[0059] It is noted that there is a difference between a first cycle of fabric deformation-recovery process and subsequent multiple cycles of the fabric deformation-recovery process. Thus, the virgin fabric without any previous deformation is deformed in the first cycle of fabric deformation-recovery process; while the deformed fabric having both recoverable and unrecoverable deformation is further deformed in the subsequent multiple cycles of fabric deformation-recovery process. However, deformed fabric having both recoverable and unrecoverable deformation is recovered in a similar way in both the first cycle and the subsequent multiple cycles of fabric deformation-recovery process.

[0060] Therefore, with reference to the Figures provided herewith, in both compression and torsion deformation processes (see Figures 6 and 7):

A_{1cp1}: total energy consumed to deform (either compress or twist) the fabric in the first cycle of the fabric deformation-recovery process in the test (excluding the deformation recovering process) (see Figures 6(a) and 7(a));

A_1: total energy consumed to deform (either compress or twist) the fabric in the second cycle (excluding the deformation recovering process); usually this energy is nearly the same as the energy consumed in the third, fourth and fifth (and any other subsequent) cycle of the fabric deformation-recovery process in the test defined by the recovery displacement ($S_0 + S_1 + S_2$) during the deformation phase (see Figures 6(b), 6(c), 7(b) and 7(c));

A_2: the work done by elastic force to recover the recoverable fabric deformation defined by the recovery displacement S_2 during the recovery phase (see Figures 6(c) and 7(c));

A_3: the work done by internal force of the deformed fabric having permanent deformation (or unrecoverable deformation) defined by the recovery displacement S_0 during the recovery process (see Figures 6(c), 6(d), 7(c) and 7(d));

A_4: the energy consumed to recover deformed fabric having both recoverable and unrecoverable deformations defined by the recovery displacement ($S_0 + S_1$) during the recovery phase (see Figures 6(b), 6(c), 7(b) and 7(c));

A_5: the energy consumed to deform the deformed fabric in the initial stage of the deformation phase defined by the recovery displacement ($S_0+S_1+S_2$) during the deformation phase (see Figure 6(c), 6(d), 7(c) and 7(d);

[0061] Thus the present inventors have arrived at the following definitions:

Fabric Sponginess (SP_i): $SP_i = A_2$;

Fabric Crispiness (CR_i): $CR_i = (A_{1cp1} - A_1) + |A_3|$;

Fabric Flexibility (FL_i): $FL_i = (A_1 - A_2) + |A_4 - A_3|$;

Fabric Stiffness (ST_i): $ST_i = (\frac{A_{1cp1}+A_1}{2})$;

Fabric Smoothness (SN): SN = dynamic friction coefficient,

where the subscript, *i*, represents the compression and torsion deformation, as appropriate.

[0062] The final fabric stiffness, sponginess, crispiness and flexibility values in the compression and torsion deformation are the average of the values in weft and warp directions, respectively.

[0063] Thus, ST, SP, CR and FL are defined as the square root of the product of their component parameters in compression and torsion deformation respectively, as follows:

Fabric Sponginess (SP): $SP = \sqrt{SP_{cp} * SP_t}$;

Fabric Crispiness (CR): $CR = \sqrt{CR_{cp} * CR_t}$;

Fabric Flexibility (FL): $FL = \sqrt{FL_{cp} * FL_t}$; and

Fabric Stiffness (ST): $ST = \sqrt{ST_{cp} * ST_t}$,

where the subscripts, *cp* and *t*, represents the compression and torsion deformation respectively.

[0064] It is also of note that, in the system developed by the inventors, fabric softness is defined as a secondary fabric handle index which is related to both fabric flexibility and fabric stiffness, thus:

Fabric Softness (SF_i): $SF_i = ST_i + FL_i$, and

Fabric Softness (SF): $SF = \sqrt{SF_{cp} * SF_t}$,.

[0065] Referring now to the other Figures provided herewith, as previously discussed, there are shown in Figures 1(A-1), 1(A-2). 1(B-1), 1(B-2), 1(C-1), 1(C-2), 1(D-1), 1(D-2), 1(E–1) and 1(E–2) examples of the compression buckling curves, illustrating the cyclic buckling and recovery behaviour of four typical sheet materials, comprising (a) a thin tightly woven fabric (120 g/m^2), (b) a very soft weft knitted fabric (380 g/m^2), (c) a standard woven wool fabric (180 g/m^2) used in the Martindale pilling test, which is very elastic and spongy (180 g/m^2), (d) a stiff white photocopy paper sheet (80 g/m^2) and (e) a very thin polyethylene cling film (4 g/m^2). It is shown that these typical materials have significant buckling properties in terms of compression modulus of fabric deformation, critical compression buckling force, stiffness of fabric deformation, and other properties, in their multiple cycles of compression buckling deformation. In addition, all the four materials also showed a very important characteristic, in that they have similar compression buckling characteristics in their own second, third, fourth and fifth cycle of compression deformation, respectively.

[0066] Turning to Figure 2(A), there is provided an illustration of an apparatus according to the invention which comprises a rotation stage 1 mounted on a base 23 and having a torque sensor 3 situated on the stage 1 and an extension-compression bidirectional load cell 8 mounted on an upper plate 9, which is fixed on a linear extension-compression stage 10, which in turn is attached to a support frame 24. A cylindrical fabric sample can then be mounted onto the surface of two cylindrical fabric sample holders 5 and 19, and tightly fixed onto the surfaces of the metal sample holders by means of clamps (not shown). The remaining numbered components comprise, *inter alia*, fixing components, including connecting members 2, 4, 6 and 7, bolts 11, 12, 13 and 14, screws 17, 21 and 22, and locking members 18 and 20, together with gaskets 15 and 16.

[0067] Whilst in no way limiting the possible operations of the apparatus according to the invention, embodiments are envisaged wherein:

(1) The lower part of the apparatus attached to sample holder 5 is static whilst the upper section attached to sample holder 19 is moveable and is able to perform compression and/or extension actions on the fabric;

(2) The upper part of the apparatus attached to sample holder 19 is static whilst the lower section attached to sample holder 5 is moveable and is able to perform compression and/or extension actions on the fabric;

(3) The lower part of the apparatus attached to sample holder 5 is static whilst the upper section attached to sample holder 19 is moveable and is able to perform twisting actions on the fabric;

(4) The upper part of the apparatus attached to sample holder 19 is static whilst the lower section attached to sample holder 5 is moveable and is able to perform twisting actions on the fabric;

(5) Both the upper part of the apparatus attached to sample holder 19 and the lower section attached to sample holder 5 are moveable and are able to perform both compression (or extension) and twisting actions on the fabric; and

(6) In any mode of operation, the apparatus may be operated whilst deployed in a horizontal orientation, rather than the vertical orientation depicted in the Figures.

[0068] Figure 2(B) provides a closer side view of a removable fabric sample holding system used in the apparatus and method according to the invention and uses numbering consistent with that in Figures 2(A), 3(A) and 3(B). Thus, a piece of rectangular fabric sample to be tested can be formed into a cylindrical shape on the surfaces of two cylinders 19 and 5 of the fabric holding system and the two edges of fabric sample in the cylindrical shape can be either left free of joints or joined together by various means such as stitches, the use of thin and soft adhesive tapes, thermal melts, and the like. The two ends of the fabric cylinder can then be clamped onto the two cylinders 19 and 5, respectively, by using clamps 25 before the holding system is slid into the grooves of the upper base 6 and lower base 4 of the apparatus to connect with both loadcell and torque sensor. Support bars 28 and 29 are used to maintain the gauge length between the two cylinders 19 and 5.

[0069] Figures 3 and 4(A) show in more detail the friction measurement system comprised in the apparatus of Figure 2(A), and Figures 3(A) and (B) illustrate two different embodiments of the system. Thus, in Figure 3(A) there is shown an embodiment of the friction management system wherein a pressure sensor 27 is mounted on the surface of the cylindrical sample holder 19, whilst in Figure 3(B) the pressure sensor 27 is mounted on the inner surface of a clamp 25. Hence, during the extension mode, wherein the sample holder 19 is moving linearly upwards driven by stage 10, the fabric sample is stationary since one of its ends is fixed on cylinder 5 by clamp 25. Therefore, there is relative movement between the sample holder 19 and the fabric sample 26, when the drag force F equals the friction force f (shown in Figure 4(A)) between the fabric sample 26 and the sample holder 19. Thereby, the pressure N exerted onto the fabric surface by the clamp 25 is obtained by means of the pressure sensor 27, and the friction force is obtained in load cell 8, shown in Figure 2. When pressure sensor 27 is mounted on the surface of the cylindrical sample holder 5 and one of the fabric ends is fixed on cylinder 19 by clamp 25, the fabric sample moves with the sample holder 19 linearly upwards driven by stage 10 during the extension mode. Therefore, there is relative movement between the sample holder 5 and the fabric sample 26 and, thereby, the pressure N exerted onto the fabric surface is measured by means of the pressure sensor 27 and the friction force is determined in load cell 8. As illustrated in Figure 4(B), the friction force decreases with increases in the displacement due to the decreases of the fabric-fabric contact area in the measuring process.

[0070] In Figures 5(A), 5(B), 5(C), 5(D), 5(E) and 5(F) there are seen graphical representations of the torsion deformation which is measured during an embodiment of the method of the invention wherein the five different material samples (three fabrics, one paper sheet and one very thin polyethylene cling film material) discussed in respect of Figure 1 were twisted by means of the rotary stage so as to impart the pure twisting mode of deformation to the fabric samples separately. It is observed that the different materials exhibit significantly different behaviour and deformation properties.

[0071] Thus, the apparatus and method according to the invention provide a means by which the fabric softness value may be assessed on the basis of the tension/compression forces, torque/angular momentum needed to deform the fabric sample when a combination of stretch, compression and twisting is performed, cyclically if necessary. Fabric handle can then be evaluated based on the fabric sponginess, fabric crispness, fabric stiffness, fabric flexibility and fabric friction properties measured.

[0072] The unique indices which may thus be derived, on the basis of the measurement system which relies on the apparatus and method of the present invention, in order to represent the fabric handle properties are duly obtained from fundamental analysis, mathematical models, and experimental information established on both small and large deformations, and an example of this system of indices system is as hereinbefore disclosed.

[0073] Throughout the description and claims of this specification, the words “comprise” and “contain” and variations of them mean “including but not limited to”, and they are not intended to (and do not) exclude other moieties, additives, components, integers or steps. Throughout the description and claims of this specification, the singular encompasses the plural unless the context otherwise requires. In particular, where the indefinite article is used, the specification is to be understood as contemplating plurality as well as singularity, unless the context requires otherwise. Specifically, in the context of the present application, the expressions “fabric”, “textile materials” and “textile product” are also to be understood as being equally applicable to mesh, film, foam and other thin sheet materials.

[0074] Features, integers, characteristics, compounds, chemical moieties or groups described in conjunction with a particular aspect, embodiment or example of the invention are to be understood to be applicable to any other aspect, embodiment or example described herein unless incompatible therewith. All of the features disclosed in this specification (including any accompanying claims, abstract and drawings), and/or all of the steps of any method or process so disclosed, may be combined in any combination, except combinations where at least some of such features and/or steps are mutually exclusive. The invention is not restricted to the details of any foregoing embodiments. The invention extends to any novel one, or any novel combination, of the features disclosed in this specification (including any accompanying claims, abstract and drawings), or to any novel one, or any novel combination, of the steps of any method or process so disclosed.

[0075] The reader's attention is directed to all papers and documents which are filed concurrently with or previous to this specification in connection with this application and which are open to public inspection with this specification, and the contents of all such papers and documents are incorporated herein by reference.

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CLAIMS

1. An apparatus for the determination of fabric handle and softness of sheet materials, said apparatus comprising:

(a) a linear displacement device;

(b) a rotary stage;

(c) at least one sample holder;

(d) a load cell;

(e) at least one pressure sensor; and

(f) a torque sensor; and

(g) a support frame.

2. An apparatus as claimed in claim 1 wherein said sheet material is a sheet material selected from sheets of paper, tissue, film, foam, mesh, non-woven material, gel, skin, leather, metal foil or composite material.

3. An apparatus as claimed in claim 1 or 2 wherein said load cell is attached to said linear displacement device.

4. An apparatus as claimed in claim 1, 2 or 3 wherein said linear displacement device is fixedly attached, directly or indirectly, to said support frame.

5. An apparatus as claimed in any one of claims 1 to 4 wherein said rotary stage is fixedly attached to a support base which is fixedly attached to said support frame.

6. An apparatus as claimed in any preceding claim wherein said torque sensor is attached to said rotary stage.

7. An apparatus as claimed in any preceding claim wherein said rotary stage and said linear displacement device are linearly spaced apart within said support frame.

8. An apparatus as claimed in any preceding claim wherein at least one sample holder is fixedly or removably, directly or indirectly, attached to said linear displacement device.

9. An apparatus as claimed in any preceding claim wherein at least one sample holder is fixedly or removably, directly or indirectly, attached to said rotary stage.

10. An apparatus as claimed in any preceding claim wherein a sample holder is attached to each of said linear displacement device and said rotary stage.

11. An apparatus as claimed in any preceding claim wherein a first sample holder is indirectly attached to said linear displacement device via said load cell and a second sample holder is indirectly attached to said rotary stage via said torque sensor.

12. An apparatus as claimed in any preceding claim wherein said at least one pressure sensor is comprised in said at least one sample holder.

13. An apparatus as claimed in any preceding claim which comprises at least one sample holder which comprises a single pressure sensor or a multiplicity of pressure sensors.

14. An apparatus as claimed in any preceding claim which comprises at least one sample holder which comprises no pressure sensor.

15. An apparatus as claimed in any preceding claim wherein said at least one sample holder comprises at least one cylindrical sample holder.

16. An apparatus as claimed in any preceding claim wherein said sample holders comprise clamping devices.

17. An apparatus as claimed in any preceding claim wherein said at least one sample holder comprises a pair of cylindrical sample holders comprising sample clamps which are adapted to hold a sample of fabric.

18. An apparatus as claimed in claim 16 wherein said at least one sample holder comprises at least one sample clamp, and wherein said at least one sample clamp comprises a single pressure sensor or a multiplicity of pressure sensors.

19. An apparatus as claimed in claim 16 wherein said at least one sample holder comprises at least one sample clamp, and wherein said at least one sample clamp comprises no pressure sensor.

20. An apparatus as claimed in any preceding claim wherein said sample holders and/or their surfaces are comprised of materials selected from wood, glass, ceramic materials, metals, metal oxides, polymeric materials, silicone gels or rubbers, natural and artificial rubbers or textile fabrics.

21. An apparatus as claimed in claim 20 wherein said polymers are selected from polyamides, polyesters, polyalkenes, PTFE, polyacrylics and polyarylenes, or copolymers thereof.

22. An apparatus as claimed in any preceding claim wherein sample holders comprise a composite surface structure incorporating at least one sensory device facilitating measurement of frictional and pressure forces.

23. An apparatus as claimed in any preceding claim wherein said linear displacement device comprises a computer controlled linear displacement device adapted to facilitate linear stretching and compression of a sample of fabric or sheet material in the linear direction of the fabric or sheet material.

24. An apparatus as claimed in claim 23 wherein said linear stretching and compression of a sample of fabric or sheet material in the linear direction of the fabric or sheet material is performed on a cyclical basis.

25. An apparatus as claimed in any preceding claim wherein said rotary stage facilitates twisting of the fabric or sheet material in the radial direction in both clockwise and anti-clockwise directions, or cyclically in both directions.

26. An apparatus as claimed in any preceding claim wherein said rotary stage is computer controlled.

27. An apparatus as claimed in any preceding claim wherein said load cell is adapted to facilitate measurement of the linear stretch/compression force.

28. An apparatus as claimed in any preceding claim wherein said torque sensor is adapted to determine the corresponding torque/angular momentum required to deform the fabric or sheet material sample radially.

29. An apparatus as claimed in any preceding claim wherein said pressure sensor is adapted to facilitate friction measurement.

30. A method for the determination of fabric handle and softness of sheet materials, said method comprising the steps of:

(a) providing an apparatus as claimed in any one of claims 1 to 29;

(b) attaching a fabric or sheet material sample to said apparatus by means of said at least one sample holder;

(c) applying at least one of:

(i) a linear stretching force and/or a linear compression force by means of said linear displacement device; and

(ii) a radial twisting force and/or torque by means of said rotary stage;

(d) determining the magnitude of the linear stretching force and/or linear compression force by means of said load cell;

(e) determining the magnitude of the radial twisting force and/or torque by means of said torque sensor; and

(f) determining the response of the fabric or sheet material to the physical deformation resulting from the application of said one or more forces and/or torque.

31. A method as claimed in claim 30 wherein the application of forces to said fabric or sheet material is carried out in order to continuously deform the fabric or sheet material.

32. A method as claimed in claim 30 wherein the application of forces to said fabric or sheet material is carried out cyclically in order to repeatedly deform the fabric or sheet material in a programmable deformation velocity and deformation length.

33. A method as claimed in claim 30, 31 or 32 wherein said fabric sample or sheet material is single layered or multilayered.

34. A method as claimed in claim 30, 31 or 32 wherein a fabric sample or sheet material is prepared with exerted bending curvature.

35. A method as claimed in claim 34 wherein said fabric sample or sheet material comprises a cylindrical tube which is either open or closed.

36. A method as claimed in claim 34 or 35 wherein said fabric or sheet material is in the form of a cylindrical tube, a curved shell or a piece of fabric or sheet material roll.

37. A method as claimed in claim 34, 35 or 36 wherein the radius of inner curvature of said fabric or sheet material sample with exerted bending curvature ranges from 0.1 mm to 200 mm.

38. A method as claimed in any one of claims 30 to 37 wherein the effective length of the fabric or sheet material sample under test ranges from 0.01 mm to 400 mm.

39. A method as claimed in any one of claims 30 to 38 wherein the ratio of the radius of the inner curvature of the fabric or sheet material cylinder to its length falls in the range of from 0.02 to 100.

40. A method as claimed in claim 39 wherein said ratio is in the range of from 0.5 to 2.

41. A method as claimed in any one of claims 30 to 40 wherein said method employs at least one of six modes of deformation process, wherein said modes are selected from pure twisting, pure stretching, pure compression, stretch-twisting, compression-twisting and friction.

42. A method as claimed in any one of claims 30 to 41 which comprises at least one of a stretch and compression measuring system, a torsion measuring system, and a friction measuring system.

43. A method as claimed in claim 42 which comprises a stretch and compression measuring system wherein the computer controlled linear displacing unit, the load cell unit, and the sample clamping unit of an apparatus as claimed in any one of claims 1 to 29 are deployed such that the displacing unit moves upwards and downwards linearly so as to exert a tension force/ compression force on the fabric or sheet material sample fixed by the clamp unit.

44. A method as claimed in claim 42 which comprises a fabric torsion measuring system wherein the computer controlled rotary stage, the torque sensor unit, and the fabric sample clamping unit of an apparatus as claimed in any one of claims 1 to 29 are deployed such that the displacing unit rotates at a constant angular speed clockwise and anti-clockwise so as to exert a radial force on the fabric sample fixed by the clamp unit.

45. A method as claimed in claim 42 which comprises a fabric friction measuring system wherein the computer controlled linear displacing unit, the sample clamping unit and the load cell unit of an apparatus as claimed in any one of claims 1 to 29 are deployed such that pressure is exerted on the fabric surface, and the friction force thereby

experienced on the fabric surface is measured by the load cell when a linear force is exerted by the computer controlled linear displacing unit so as to displace the sample.

46. A method as claimed in any one of claims 30 to 45 which facilitates the determination of at least one property selected from torsion force, torque, stretch force, extension, compression and torsion modulus of deformation, Poisson's ratio, compression force, stiffness of deformation, number of patterned creases or wrinkles on the fabric or sheet material surface, friction force and friction co-efficient.

47. A method as claimed in any one of claims 30 to 46 which facilitates the determination of at least one property selected from critical buckling forces in compression and torsion deformation, coefficients of extensional stiffness parameter (C) and bending parameter (D), wave speed of compression buckling (c_1) and wave speed of torsion buckling (c_2).

48. A method as claimed in any one of claims 30 to 47 whenever performed using an apparatus as claimed in any one of claims 1 to 29.

49. A method for the determination of fabric handle indices, said method comprising the steps of:

(a) performing the method as claimed in any one of claims 30 to 48; and

(b) determining at least one of the indices of fabric sponginess (SP), fabric crispness (CR), fabric flexibility (FL), fabric stiffness (ST) and fabric smoothness (SN) from the measured values obtained.

50. A method as claimed in claim 49 which further comprises the step of calculating the fabric softness index SF.

51. A method for determining the index of fabric sponginess, said method comprising determining the work done (A_2) by elastic force to recover the recoverable fabric deformation defined by the recovery displacement S_2 during the recovery phase, and calculating the index therefrom.

52. A method for determining the index of fabric crispness, said method comprising determining the total energy (A_{1cp1}) consumed to deform the fabric in the first cycle of the fabric deformation-recovery process in the test, determining the total energy (A_1) consumed to deform the fabric in the second cycle of the fabric deformation-recovery process in the test defined by the recovery displacement (S_0 + S_1 + S_2) during the deformation phase, determining the work done (A_3) by internal force of the deformed fabric having permanent deformation (or unrecoverable deformation) defined by the recovery displacement S_0 during the recovery process, and calculating the index therefrom.

53. A method for determining the index of fabric flexibility, said method comprising determining the total energy (A_1) consumed to deform the fabric in the second cycle of the fabric deformation-recovery process in the test defined by the recovery displacement (S_0 + S_1 + S_2) during the deformation phase, determining the work done (A_2) by elastic force to recover the recoverable fabric deformation defined by the recovery displacement S_2 during the recovery phase, determining the work done (A_3) by internal force of the deformed fabric having permanent deformation (or unrecoverable deformation) defined by the recovery displacement S_0 during the recovery process, determining the energy (A_4) consumed to recover deformed fabric having both recoverable and unrecoverable deformations defined by the recovery displacement (S_0 + S_1) during the recovery phase, and calculating the index therefrom.

54. A method for determining the index of fabric stiffness, said method comprising determining the total energy (A_{1cp1}) consumed to deform the fabric in the first cycle of the fabric deformation-recovery process in the test, determining the total energy (A_1) consumed to deform the fabric in the second cycle of the fabric deformation-recovery process in the test defined by the recovery displacement (S_0 + S_1 + S_2) during the deformation phase, and calculating the index therefrom.

55. A method for determining the index of fabric smoothness, said method comprising determining the dynamic friction coefficient and calculating the index therefrom.

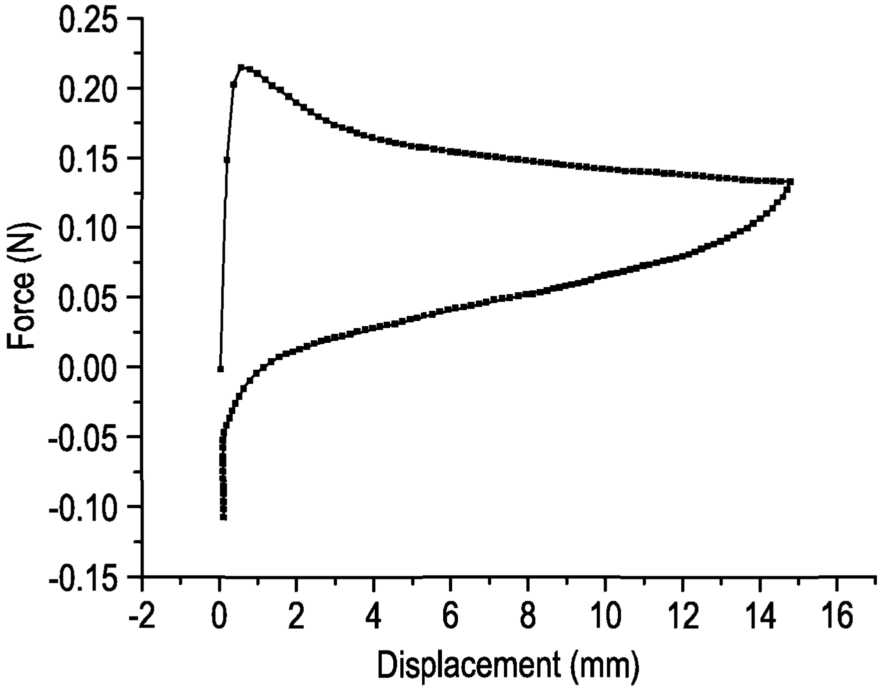


FIG. 1(A-1)

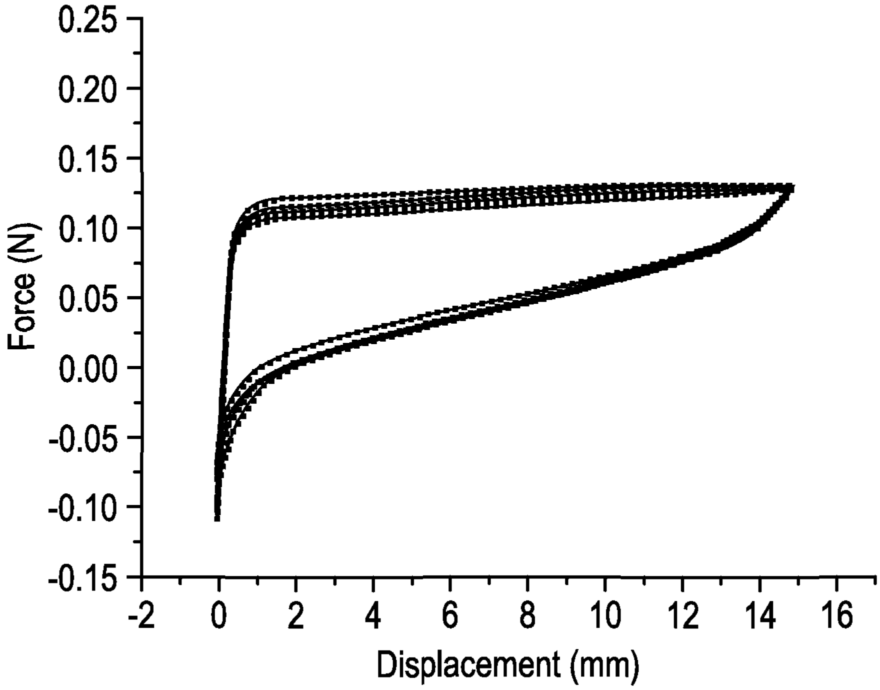


FIG. 1(A-2)

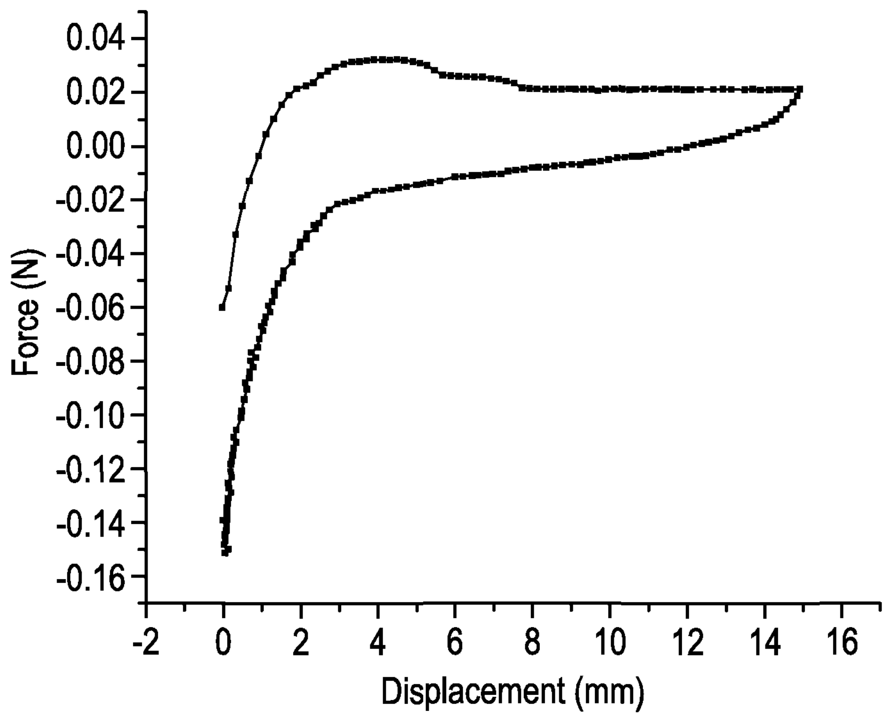


FIG. 1(B-1)

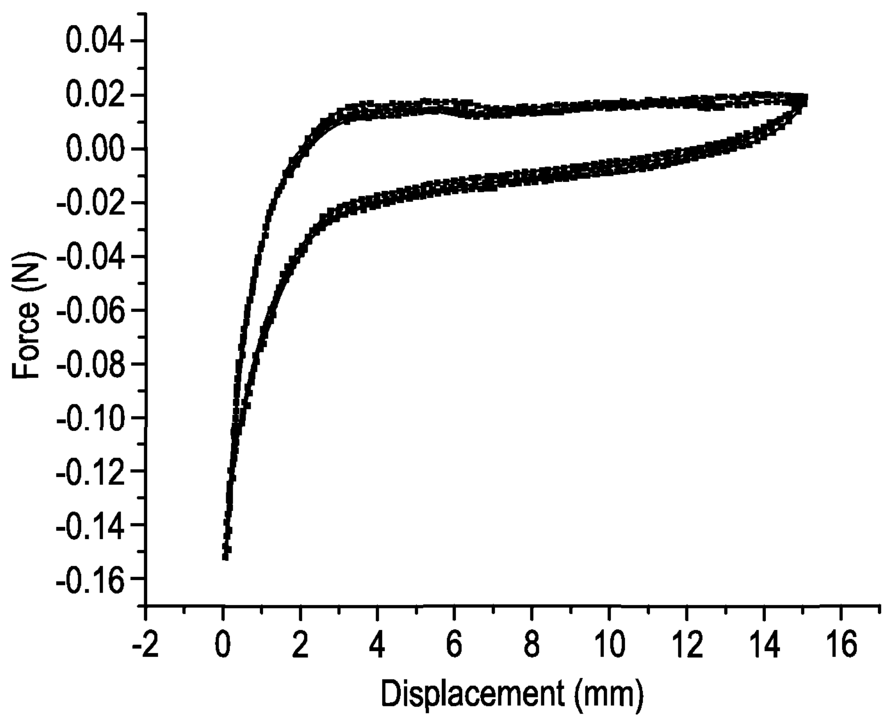


FIG. 1(B-2)

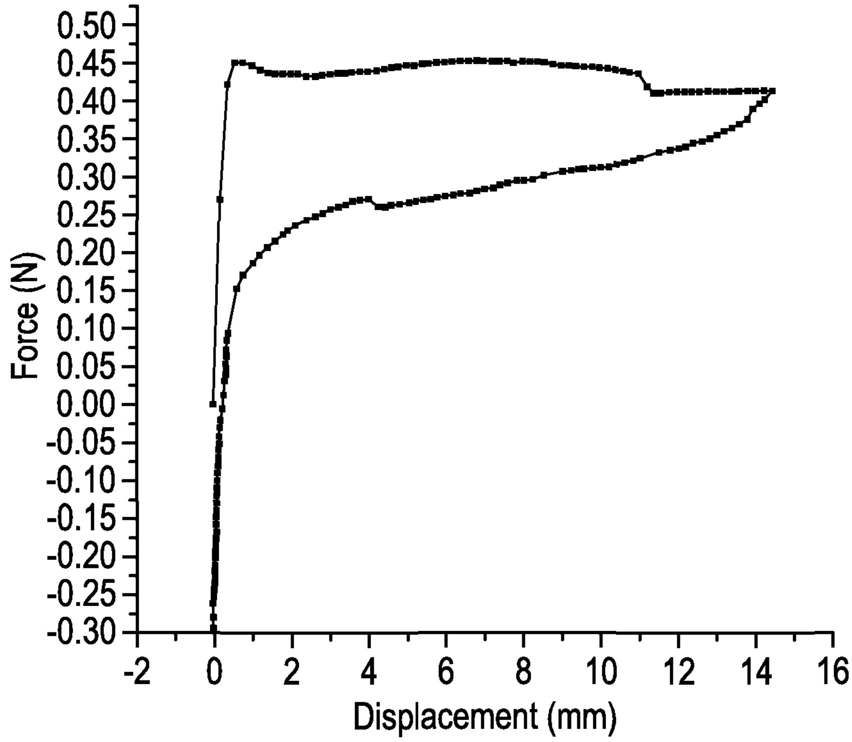


FIG. 1(C-1)

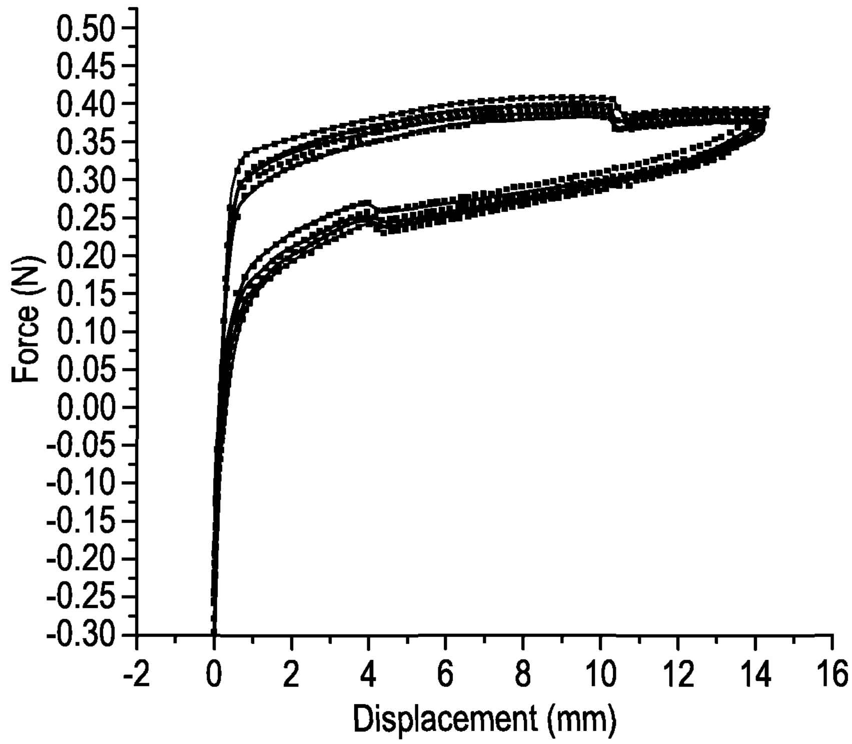


FIG. 1(C-2)

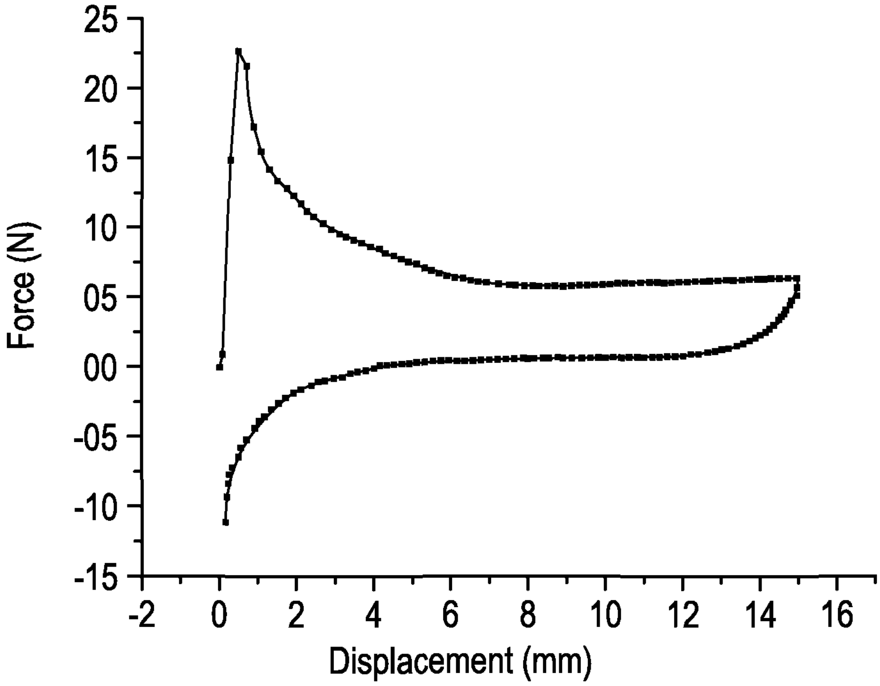


FIG. 1(D-1)

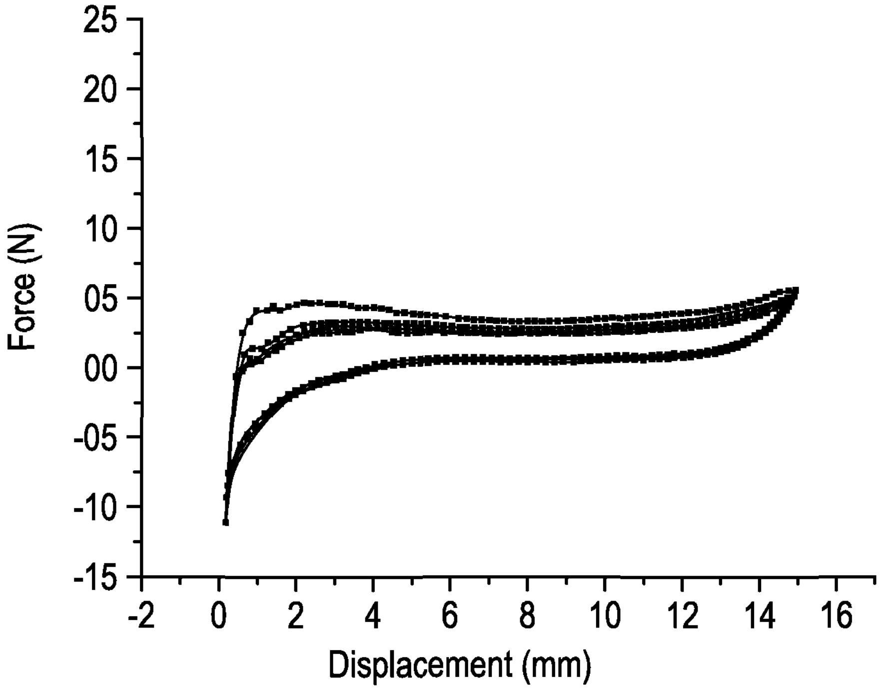


FIG. 1(D-2)

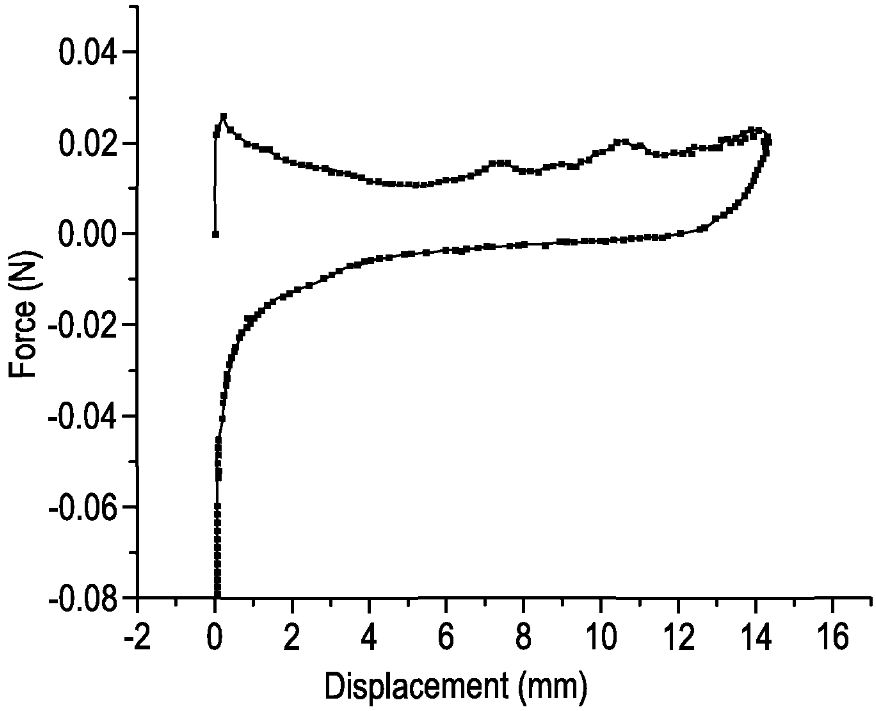


FIG. 1(E-1)

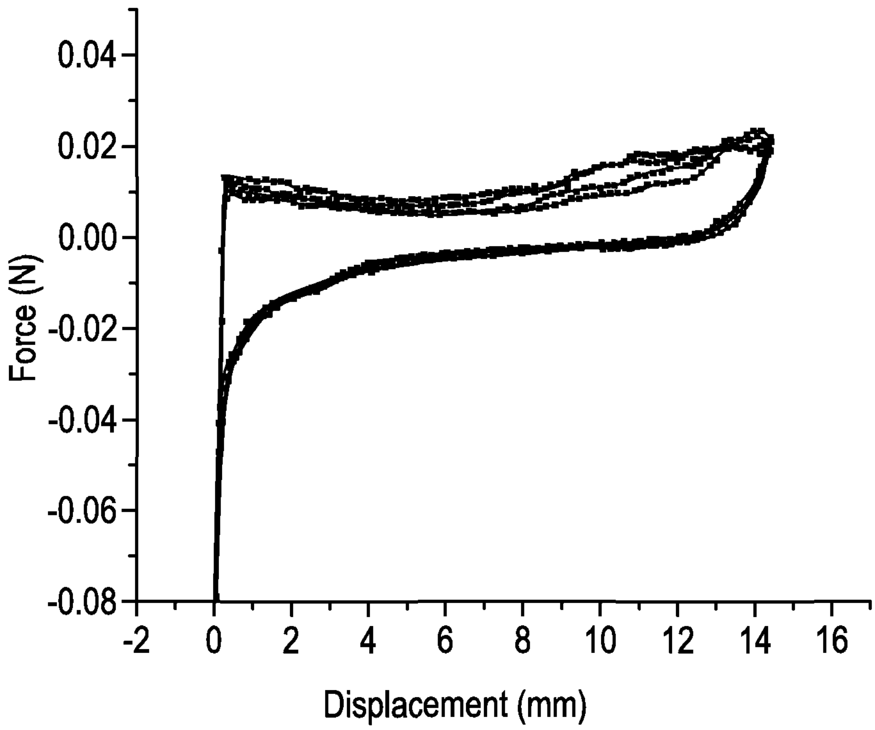


FIG. 1(E-2)

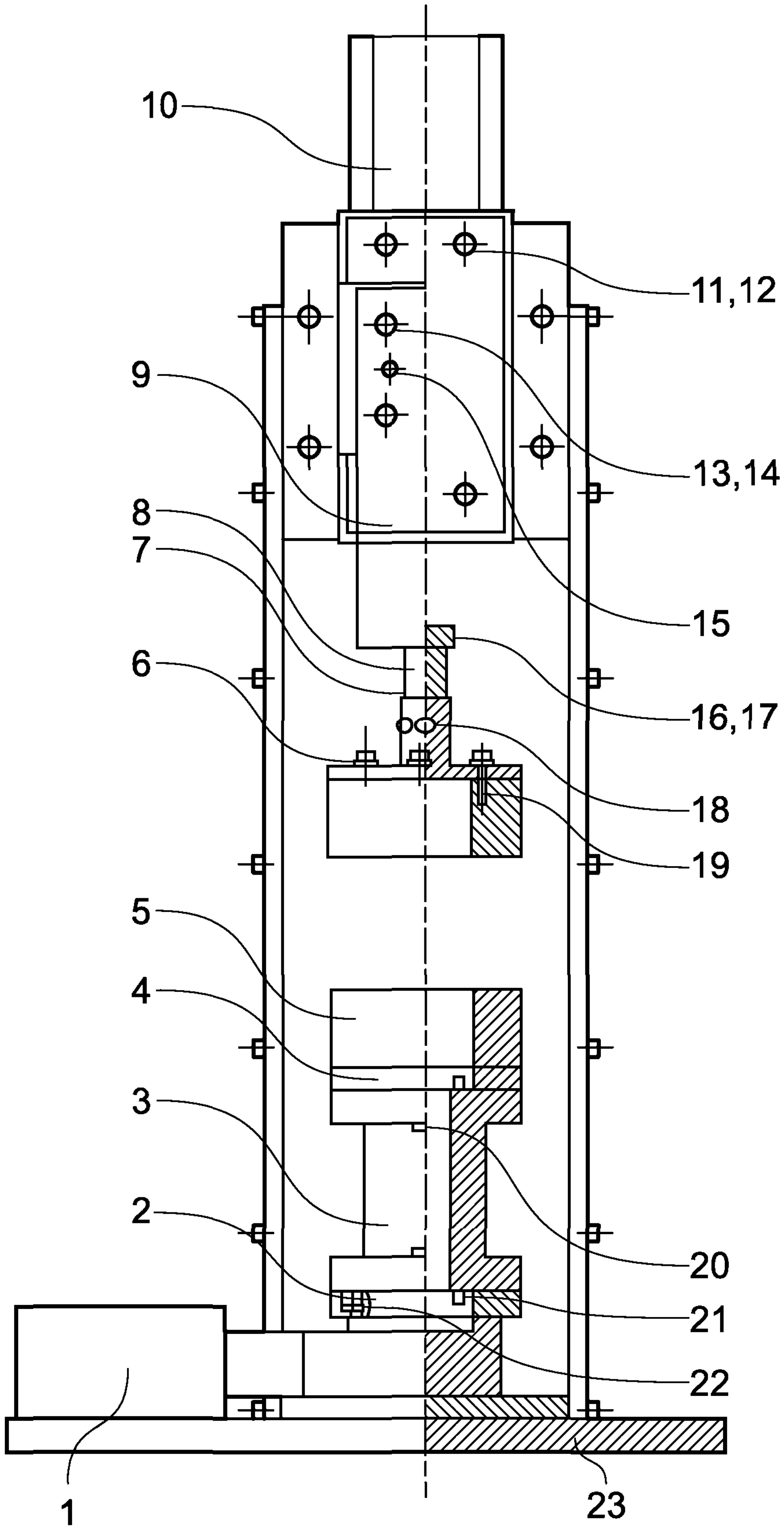


FIG. 2A

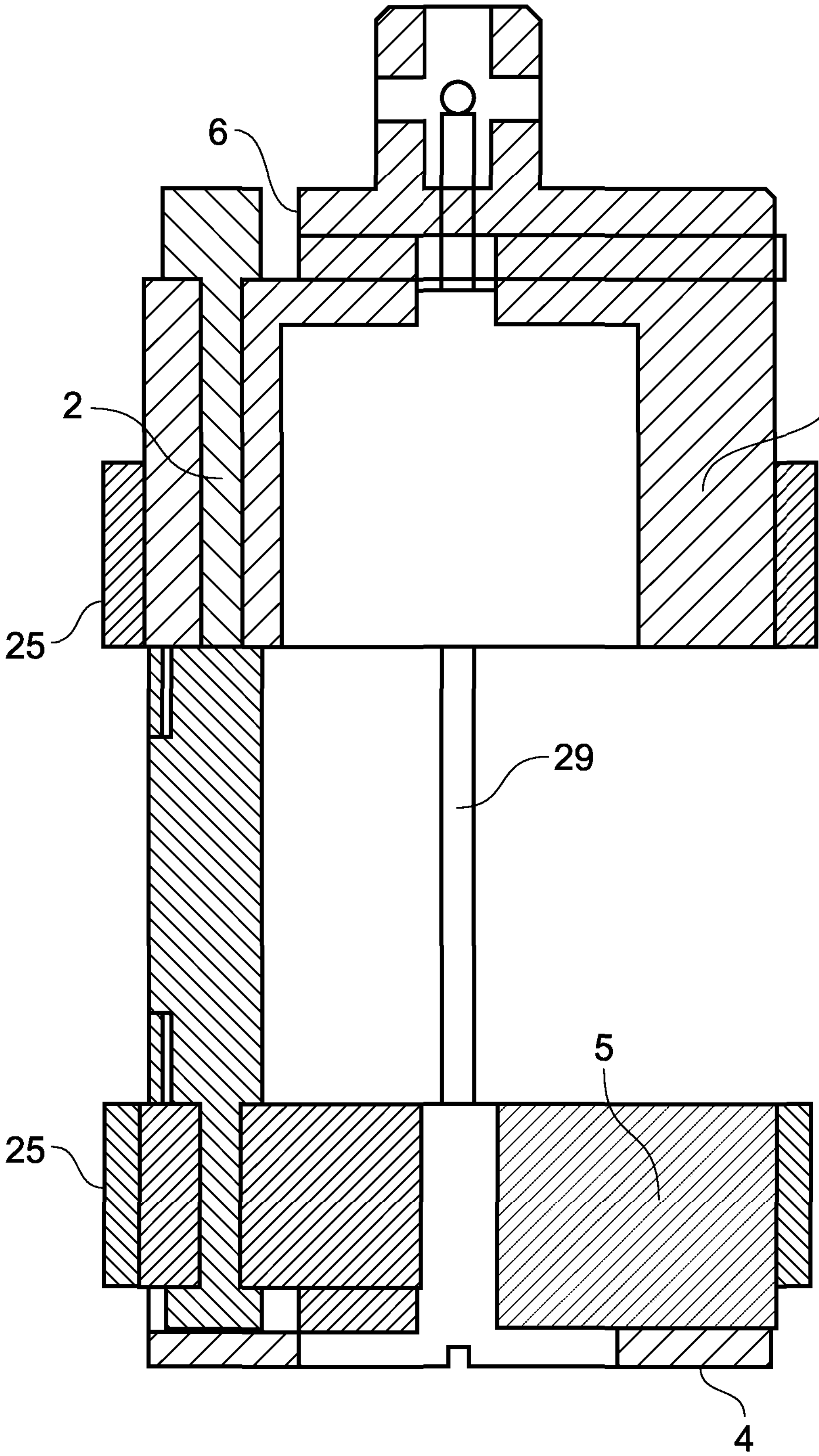


FIG. 2B

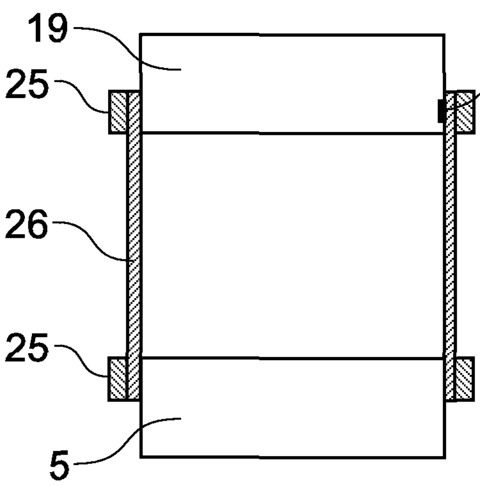


FIG. 3A

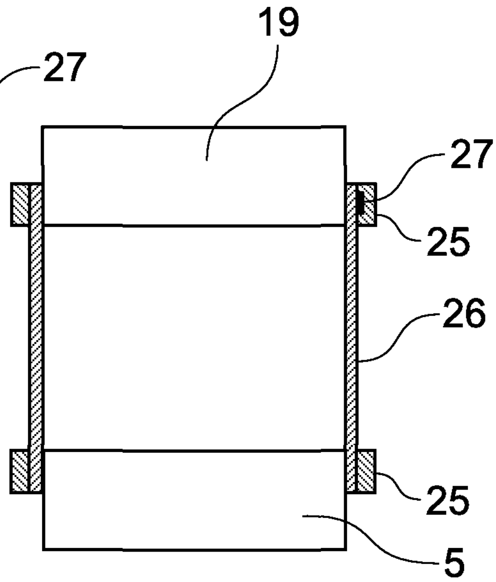


FIG. 3B

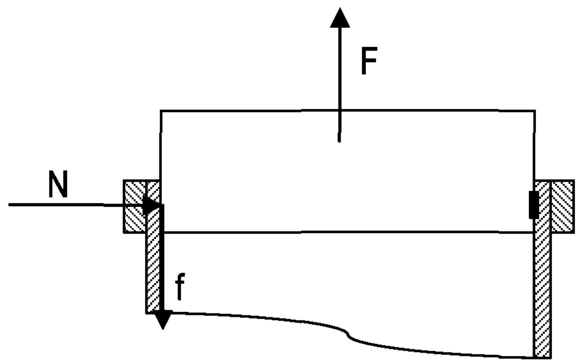


FIG. 4A

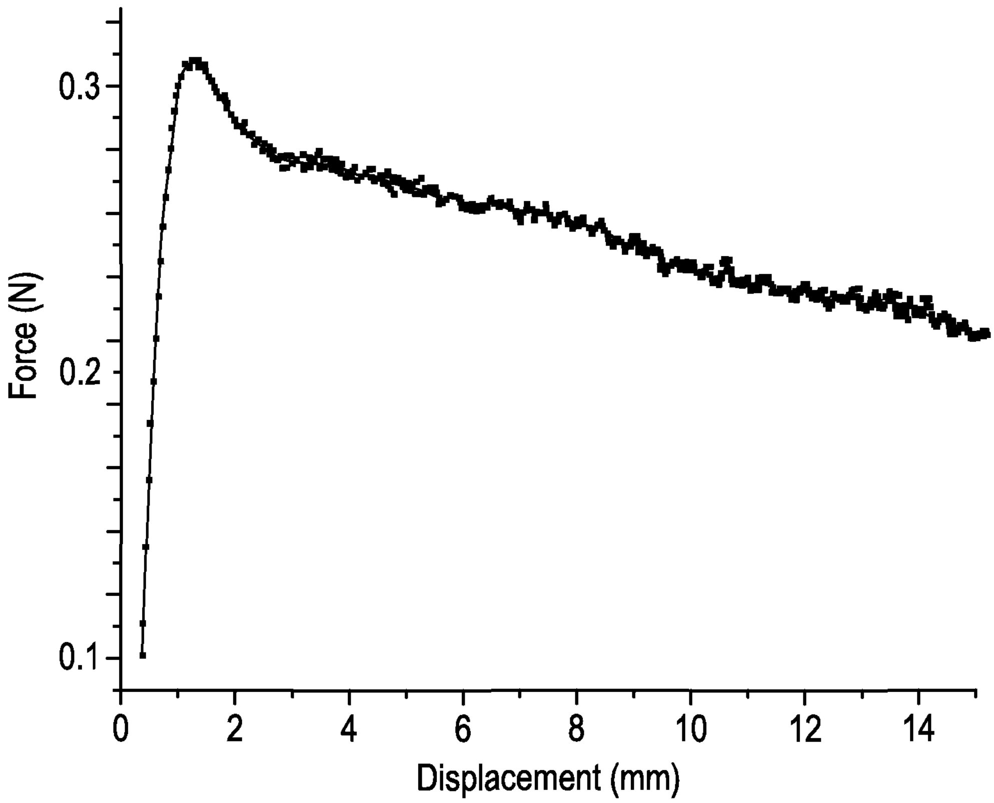
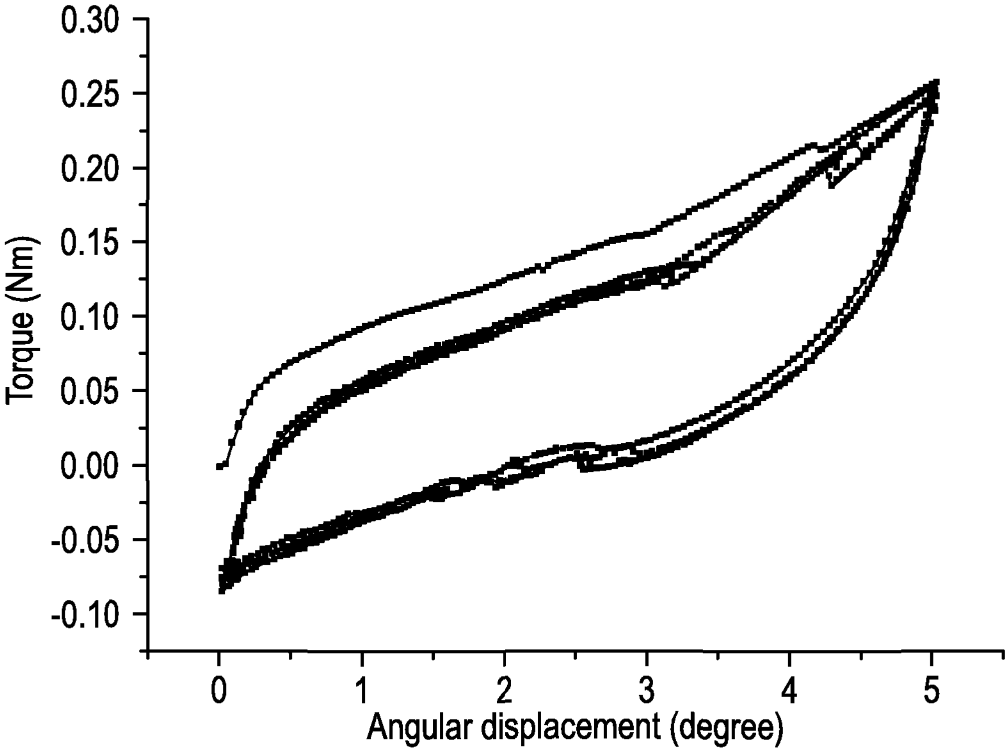
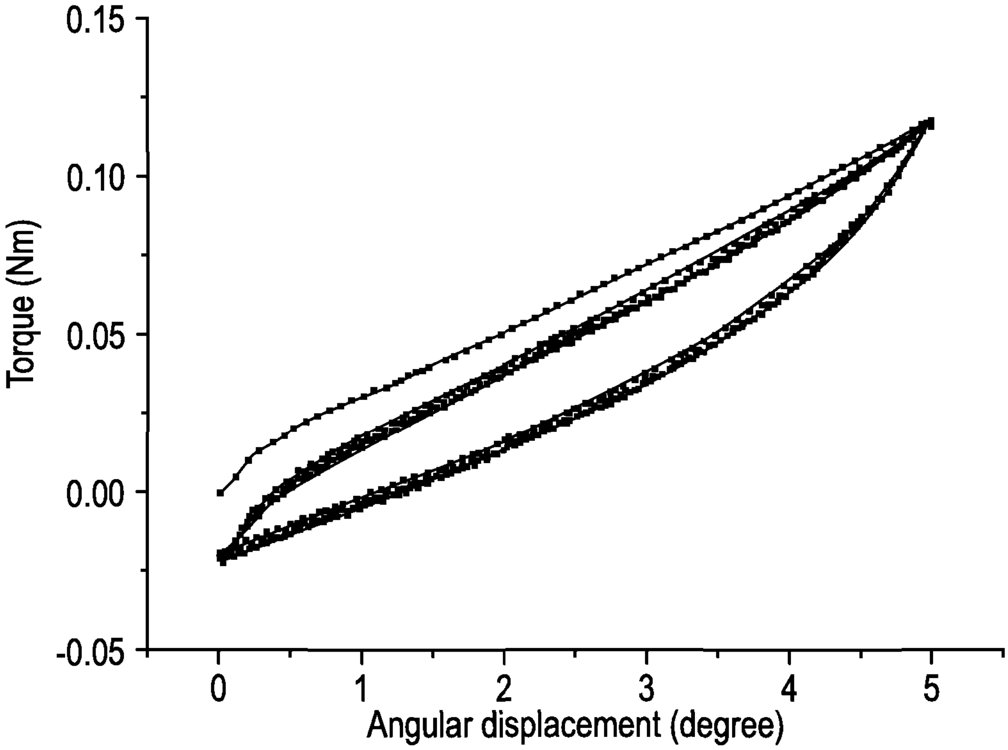


FIG. 4B



Torque (Nm)
0.30
0.25
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
0
1
2
3
4
5
Angular displacement (degree)

FIG. 5A



Torque (Nm)
0.15
0.10
0.05
0.00
-0.05
0
1
2
3
4
5
Angular displacement (degree)

FIG. 5B

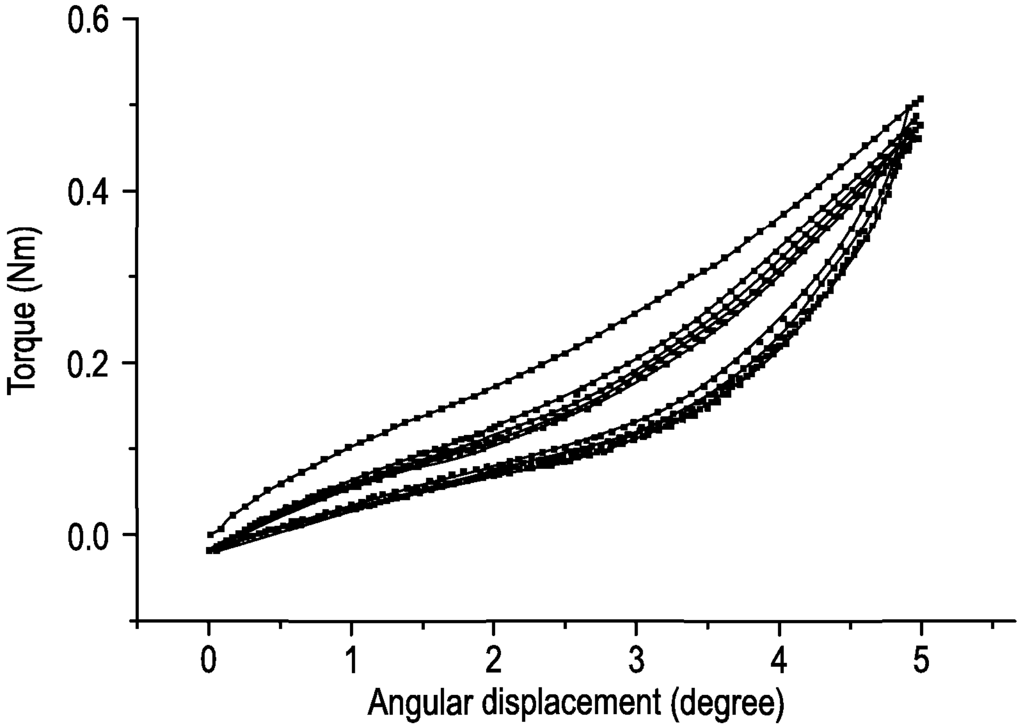

0.6
0.4
0.2
0.0
Torque (Nm)
0
1
2
3
4
5
Angular displacement (degree)

FIG. 5A

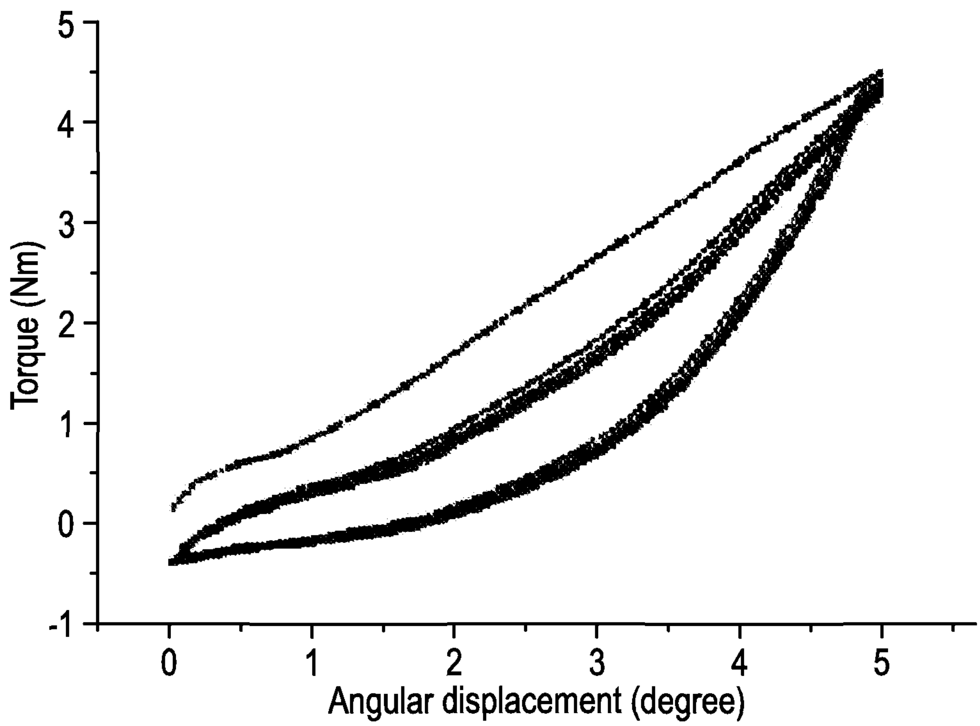

5
4
3
2
1
0
-1
Torque (Nm)
0
1
2
3
4
5
Angular displacement (degree)

FIG. 5B

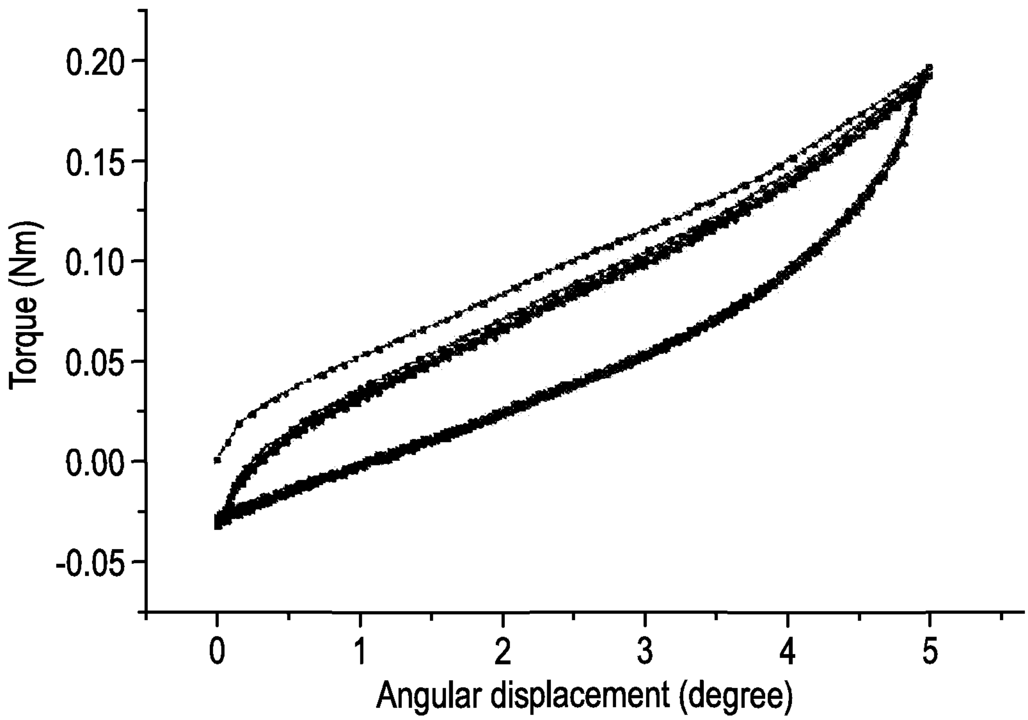

0.20
0.15
0.10
0.05
0.00
-0.05
Torque (Nm)
0
1
2
3
4
5
Angular displacement (degree)

FIG. 5E

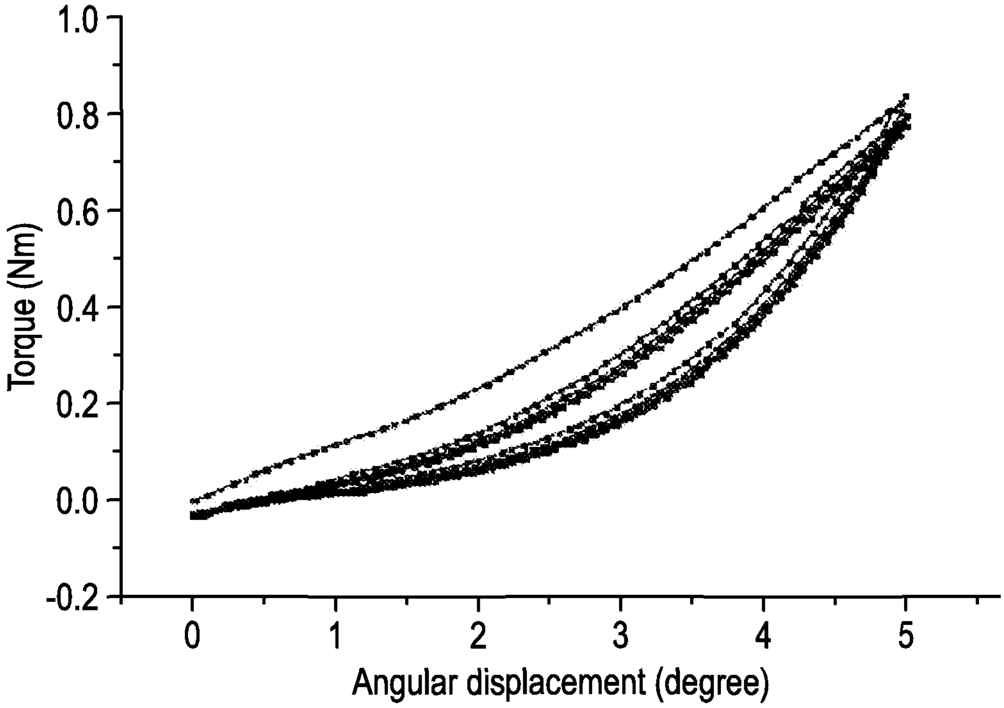

1.0
0.8
0.6
0.4
0.2
0.0
-0.2
Torque (Nm)
0
1
2
3
4
5
Angular displacement (degree)

FIG. 5F

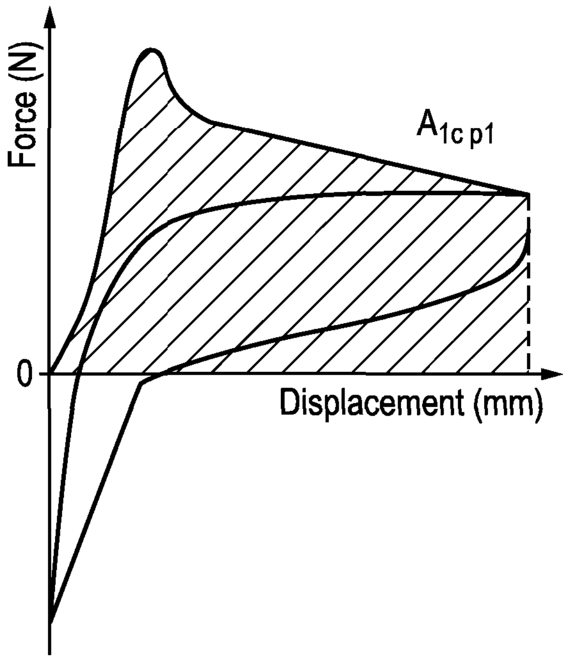


FIG. 6A

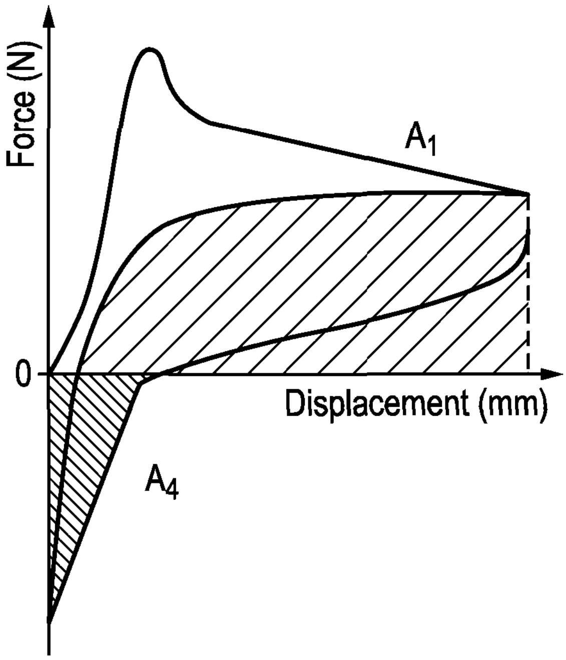


FIG. 6B

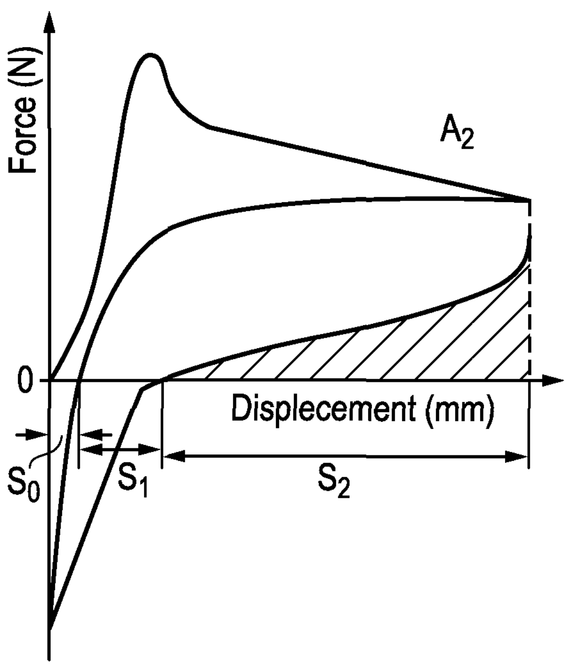


FIG. 6C

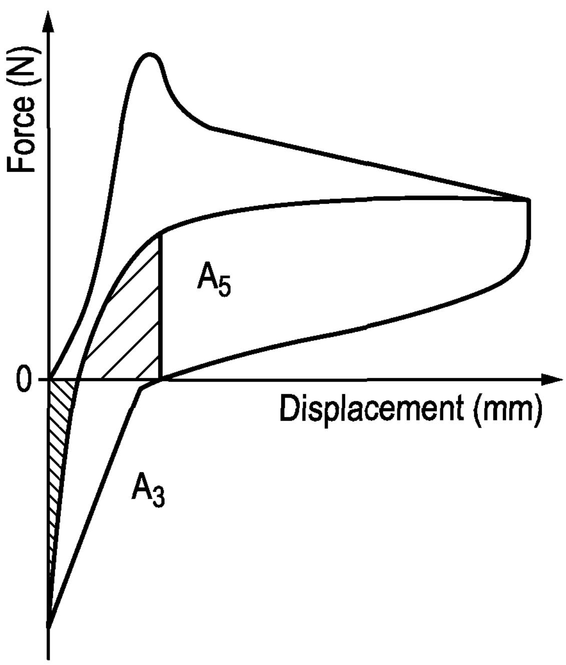


FIG. 6D

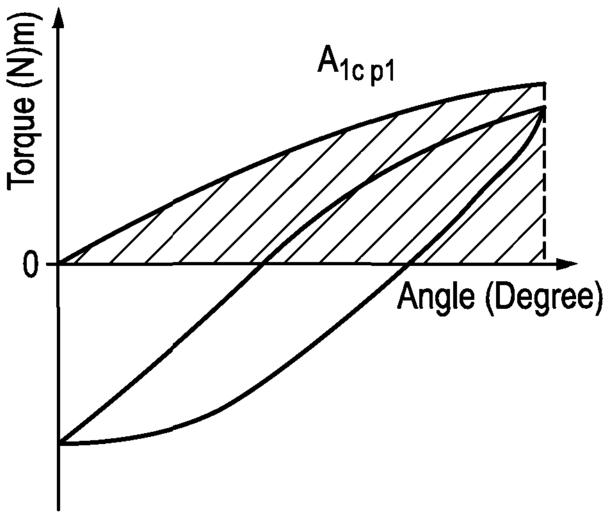


FIG. 7A

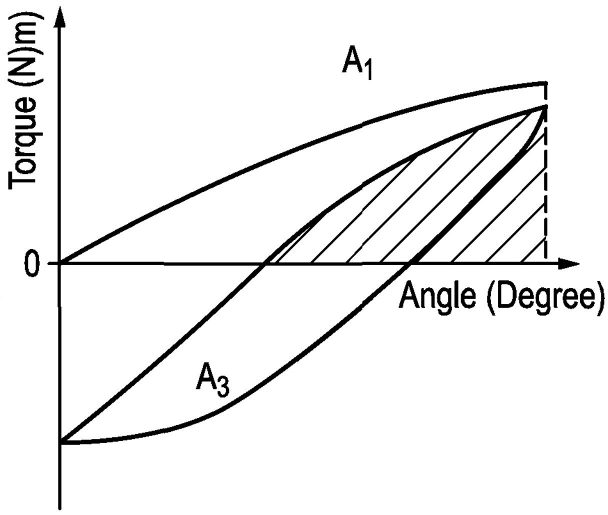


FIG. 7B

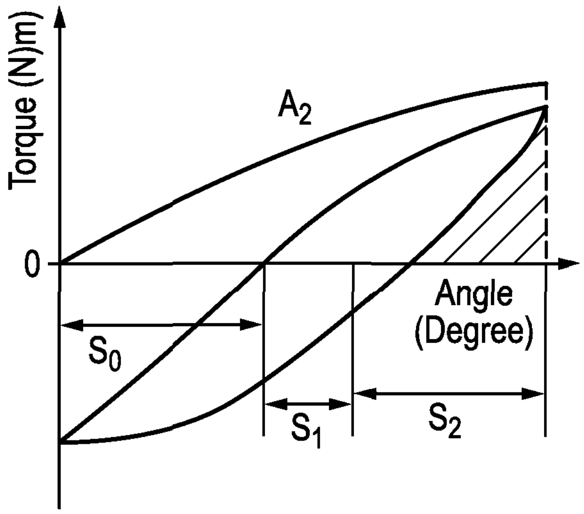


FIG. 7C

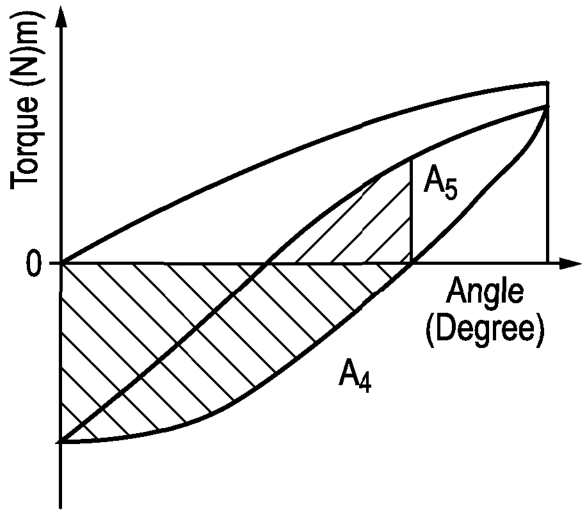


FIG. 7D