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Viscoelastic or Viscoplastic Glucose Theory (VGT #48): Investigating the Role of Strain, Strain Rate, and the Viscosity Factor in Biomedical VGT Applications Using Sensor FPG versus Body Weight Over 18 Months from 10/1/2020 to 3/23/2022, Along with Finger FPG versus Body Weight Over 11 Years from 1/1/2012 to 3/23/2022, with Biomedical Illustrations of the Physics and Engineering Analysis Results Based on the GH-Method: Math-Physical Medicine (No. 633)

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Note: Readers who want to get a quick overview can read the abstract, results, and graphs.

Abstract

The author was a professional engineer working in the fields of the space shuttle, naval battleships, nuclear power plant, computer hardware and software, artificial intelligence, and semiconductor chips. After retiring from his work based in the disciplines of mathematics, physics, and engineering, he has initiated self-study and research on internal medicine with an emphasis on biomarker relationships exploration and disease prevention. Since 2010, he has utilized these disciplines learned from 7 different universities along with work experiences to formulate his current medical research work. One thing he has learned is that in engineering or medicine, we are seeking answers or illustrations for the relationships between the input variable (force on a structure or cause of a disease) and output variable (deformation on a structure or symptom of a disease). However, the relationships between input and output could be expressed with a matrix format of 1 x 1, 1 x n, m x 1, or m x n (m or n means different multiple variables). In addition to the described complications, the output resulting from one or more inputs can turn into another input of different outputs, i.e., a symptom of certain causes can be a cause of the different symptoms. This phenomenon becomes a complex chain "effect". In other words, an engineering or biomedical issue is fundamentally a mathematical problem that correlates with many inherent physical laws or principles. Over the past 13 years, he has investigated approximately 100 different sets of cause/input variables versus symptom/output variables in the biomedical field. For example, food and exercise influence the glucose level, where persistent high glucose can result in diabetes. When diabetes combines with hypertension (high blood pressure) and hyperlipidemia (high blood lipids), it can cause cardiovascular diseases. Furthermore, diabetes is also linked with various kinds of cancers. These sets of biomedical input versus output scenarios and problems have been researched by the author using different tools from mathematics, physics, computer science, and engineering. Recently, he has applied theories of viscoelasticity and viscoplasticity to various biomedical problems and has written nearly 50 papers. In this article, he selected two datasets to investigate the role played by strain, stress, strain rate, viscosity factor, and relative energy. The first dataset is a symptom of the sensor collected fasting plasma glucose (FPG) versus a cause of body weight (BW) during the 18 months from October 2020 to March 2022. The second dataset is a symptom of the finger pierced FPG versus a cause of BW during the 11 years from Y2012 to Y2022. The appearance of the two waveforms in the time domain is quite different due to two selected time windows and two glucose measurement methods. The following defined equations are used to establish the stress-strain diagram in a space domain (SD): Strain = ε (FPG) = individual FPG at the present time. Stress = σ (based on the change rate of strain, FPG, multiplying with a viscosity factor, BW) = η * (dε/dt) = η * (d-strain/d-time) = (viscosity factor η using individual BW at present time) * (FPG at

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present time - FPG at a previous time). However, the measurement units for glucose (mg/dL) and BW (pounds) were defined long ago without deep thinking of their biomedical means in terms of their inherent inter-relationships. To place them on even ground with a sufficient biomedical sense, the author has normalized the viscosity factor η of BW using the following formula: Normalized BW = BW / 170, where he uses 170 due to his body height of 5'9.5" (176.5 cm), a 170 lbs. (77.3 kg) of BW would provide a healthy BMI level of 25.0. To offer a simple explanation to readers who do not have a physics or engineering background, the author includes a brief excerpt from Wikipedia regarding the description of basic concepts for elasticity and plasticity theories, viscoelasticity, and viscoplasticity theories from the disciplines of engineering and physics in the method section. In conclusion, using the Biomedical VGT approach, he developed and learned the following important concepts: (1) The stress or σ, i.e. influential force or cause of disease symptom ε, has two key parts. The first part is the symptom change versus time or dε/dt, i.e. symptom change rate. The change rate of symptom, strain rate, or dε/dt, not only demonstrates the importance of time-dependence characteristics of biomedical variables but also controls the stress-strain curve shape, including its vertical moving direction on the stress-strain diagram i.e., cause-symptom diagram. The second part is the influential force of the symptom, i.e. the viscosity factor or η. The viscosity factor η partially controls the magnitude of stress, i.e. magnitude of the influential force of disease symptoms. This influential force or disease cause, the viscosity factor η, further determines the range of the y-axis in the stress-strain diagram. (2) The strain data scale of a symptom (strain or ε) determines the range of the x-axis in the stress-strain diagram and indicates the range of the symptom's fluctuations within a selected time window. (3) The stress-strain curve (the cause-symptom curve) inside the confined rectangular space with a dimension of x-axis range and y-axis range could provide a useful indication of the maximum possible relative energy associated with the cause-symptom variance with time. This relative energy value offers a clear picture of the severity of the symptom at different time points and the estimated time requirement of developing into a certain disease (i.e., organ damages resulting from the energy). This concept and process provide a useful tool for disease prevention. In addition, the following four numerical descriptions offer a more quantitative illustration for the above-mentioned conclusive remarks: (1) These two stress-strain curves have different shapes and appearances which are a result of two different patterns of FPG change rates. They are further related to two different time windows of collected data (a factor having more impact) and two different glucose measurement methods (a factor having less impact). These two ranges of FPG data rates are shown on the y-axis as 20, between -10 and +10, for the 18-month sensor FPG, and 20, between -15 and +5, for the 11-year finger FPG. From a biomedical view, this strain rate, glucose change rate, is equivalent to the meaning of the existing medical terminologies: glucose fluctuation (GF) or glycemic variability (GV) which are indicators of energy associated with glucose waves and are important elements in diabetes control. (2) The sensor FPG of 18-months has shown a pseudo viscoelastic behavior pattern with a closed loop. Its starting FPG is 93 mg/dL and ending FPG is 95 mg/dL due to the author's type 2 diabetes (T2D) conditions have been under control during the timeframe of 2020-2022. On the contrary, the finger FPG of 11-years has shown a viscoplastic behavior pattern with a big opening of the loop. Its starting FPG is 145 mg/dL and ending FPG is 95 mg/dL due to the author's T2D conditions continuously improving during the timeframe from Y2012 to Y2022. These two FPG data ranges are shown on the x-axis as 24, between 87 and 111, for the 18-month sensor FPG and 51, between 94 and 145, for the 11-year finger FPG. (3) To demonstrate the role and influence power of cause, i.e., viscosity factor or η, the author has created two extra datasets for "verification purposes". The first dataset, BW-1, is multiplying his measured BW by 1.2 (boosting every BW value by 20%). The second dataset, BW-2, is changing his measured BW by a sequence order of +0, +30, and -30. With this BW-2 modification, he hopes to create a "zig-zag" type or an up-and-down curve pattern. The end results from the modified BW-1 and BW-2 are (a) the hysteresis loop area of BW-1 is 20% larger than BW, and (2) the hysteresis loop area of BW-2 is almost equal to BW. These two experiments have proven that the viscosity factor η (cause of symptom) or BW, provides an enlarging or shrinking effect on the hysteresis loop area by changing its overall magnitude. (4) The x-axis range is 24 (between 87 and 111) for the 18-month sensor FPG and 51 (between 94 and 145) for the 11-year finger FPG. The y-axis range is 20 (between -10 and +10) for the 18-month sensor FPG and 20 (between -15 and +5) for the 11-year finger FPG. Therefore, the maximum areas of two rectangular spaces are 480 (= 24*20) for the 18-month sensor FPG, and 1,020 (=51*20) for the 11-year finger FPG. The maximum rectangular area ratio is 2.13 (= 1020 / 480). However, using the trapezoid formula to calculate the real hysteresis loop areas, the two hysteresis loop areas are 208 (43% of 480) for the 18-month sensor FPG and 362 (35% of 1020) for the 11-year finger FPG. The hysteresis loop area ratio is 1.74 (= 362 / 208). From either the estimated rectangular areas or the calculated hysteresis loop areas, although the area ratios are different, we still can get a rough idea of energy generated (uploading) and dissipated (unloading) during the process of the FPG changes resulting from BW changes. This means that the longer his diabetes conditions last while being overweight, the more energy his body

would carry resulting in the eventual damage to multiple internal organs. On contrary, over the past 18 months period from October/2020 to March/2022, his total energy carried inside his body resulting from FPG and BW is only 57% (= 208/362) using the hysteresis loop areas, and 47% (480/1020) using the estimated rectangular areas when compared against the past 11-years from Y2012 to Y2022. This lower energy level of 47% (using hysteresis loop area) over the past 18 months is a result of better health conditions in terms of both glucose and weight in comparison to the higher energy of 100% during the longer 11 years period which covers many earlier years with unhealthy conditions. The above conclusions have illustrated his quantitative study results of the relationship between body weight and fasting glucose using the theories of viscoelasticity and viscoplasticity. The relationship between obesity, diabetes, and some life-threatening complications, such as heart attacks or cancers, can be explored and investigated using certain available tools from physics and engineering. This method can even be applied to estimating the timeframe for a patient to develop certain critical diseases.

Keywords: Viscoelastic; Viscoplastic; Strain; Strain rate; Viscosity factor; Fasting plasma glucose; Postprandial plasma glucose; Body weight

Abbreviations: BW: body weight; PPG: postprandial plasma glucose; FPG: fasting plasma glucose; SD: space domain; MPM: math-physical medicine

1. INTRODUCTION

The author was a professional engineer working in the fields of the space shuttle, naval battleships, nuclear power plant, computer hardware and software, artificial intelligence, and semiconductor chips. After retiring from his work based in the disciplines of mathematics, physics, and engineering, he has initiated self-study and research on internal medicine with an emphasis on biomarker relationships exploration and disease prevention. Since 2010, he has utilized these disciplines learned from 7 different universities along with work experiences to formulate his current medical research work.

One thing he has learned is that in engineering or medicine, we are seeking answers or illustrations for the relationships between the input variable (force on a structure or cause of a disease) and output variable (deformation on a structure or symptom of a disease). However, the relationships between input and output could be expressed with a matrix format of 1 x 1, 1 x n, m x 1, or m x n (m or n means different multiple variables). In addition to the described complications, the output resulting from one or more inputs can turn into another input of different outputs, i.e., a symptom of certain causes can be a cause of the different symptoms. This phenomenon becomes a complex chain "effect". In other words, an engineering or biomedical issue is fundamentally a mathematical problem that correlates with many inherent physical laws or principles.

Over the past 13 years, he has investigated approximately 100 different sets of cause/input variables versus symptom/output variables in the biomedical field. For example, food and exercise influence the glucose level, where persistent high glucose can result in diabetes. When diabetes combines with hypertension (high blood pressure) and hyperlipidemia (high blood lipids), it can cause cardiovascular diseases. Furthermore, diabetes is also linked with various kinds of cancers. These sets of biomedical input versus output scenarios and problems have been researched by the author using different tools from mathematics, physics, computer science, and engineering.

Recently, he has applied theories of viscoelasticity and viscoplasticity to various biomedical problems and has written nearly 50 papers. In this article, he selected two datasets to investigate the role played by strain, stress, strain rate, viscosity factor, and relative energy. The first dataset is a symptom of the sensor collected fasting plasma glucose (FPG) versus a cause of body weight (BW) during the 18 months from October 2020 to March 2022. The second dataset is a symptom of the finger pierced FPG versus a cause of BW during the 11 years from Y2012 to Y2022. The appearance of the two waveforms in the time domain is quite different due to two selected time windows and two glucose measurement methods.

The following defined equations are used to establish the stress-strain diagram in a space domain (SD):

Strain
= ε (FPG)
= individual FPG at the present time

Stress
= σ (based on the change rate of strain, FPG, multiplying with a viscosity factor, BW)
= η * (dε/dt)
= η * (d-strain/d-time)
= (viscosity factor η using individual BW at present time) * (FPG at present time - FPG at a previous time)

However, the measurement units for glucose (mg/dL) and BW (pounds) were defined long ago without deep thinking of their biomedical means in terms of their inherent inter-relationships. To place them on even ground with a sufficient biomedical sense, the author has normalized the viscosity factor η of BW using the following formula:

Normalized BW = BW / 170

Where he uses 170 due to his body height of 5'9.5" (176.5 cm), a 170 lbs. (77.3 kg) of BW would provide a healthy BMI level of 25.0.

To offer a simple explanation to readers who do not have a physics or engineering background, the author includes a brief excerpt from Wikipedia regarding the description of basic concepts for elasticity and plasticity theories, viscoelasticity, and viscoplasticity theories from the disciplines of engineering and physics in the method section.

2. METHODS

2.1 Elasticity, plasticity, viscoelasticity and viscoplasticity

The difference between elastic materials and viscoelastic materials (from "Soborthans, innovating shock and vibration solutions").

What are elastic materials?

Elasticity is the tendency of solid materials to return to their original shape after forces are applied on them. When the forces are removed, the object will return to its initial shape and size if the material is elastic.

What are viscous materials?

Viscosity is a measure of a fluid's resistance to flow. A fluid with large viscosity resists motion. A fluid with low viscosity flows. For example, water flows more easily than syrup because it has a lower viscosity. High viscosity materials might include honey, syrups, or gels – generally things that resist flow. Water is a low viscosity material, as it flows readily. Viscous materials are thick or sticky or adhesive. Since heating reduces viscosity, these materials don't flow easily. For example, warm syrup flows more easily than cold.

What is viscoelastic?

Viscoelasticity is the property of materials that exhibit both viscous and elastic characteristics when undergoing deformation. Synthetic polymers, wood, and human tissue, as well as metals at high temperature, display significant viscoelastic effects. In some applications, even a small viscoelastic response can be significant.

Elastic behavior versus viscoelastic behavior

The difference between elastic materials and viscoelastic materials is that viscoelastic materials have a viscosity factor and the elastic ones don't. Because viscoelastic materials have the viscosity factor, they have a strain rate dependent on time. Purely elastic materials do not dissipate energy (heat) when a load is applied, then removed; however, a viscoelastic substance does.

The following brief introductions are excerpts from Wikipedia:

"Elasticity (physics):

The physical property when materials or objects return to original shape after deformation.

In physics and materials science, elasticity is the ability of a body to resist a distorting influence and to return to its original size and shape when that influence or force is removed. Solid objects will deform when adequate loads are applied to them; if the material is elastic, the object will return to its initial shape and size after removal. This is in contrast to plasticity, in which the object fails to do so and instead remains in its deformed state.

The physical reasons for elastic behavior can be quite different for different materials. In metals, the atomic lattice changes size and shape when forces are applied (energy is added to the system). When forces are removed, the lattice goes back to the original lower energy state. For rubbers and other polymers, elasticity is caused by the stretching of polymer chains when forces are applied.

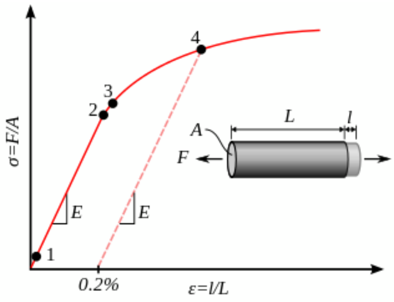
Hooke's law states that the force required to deform elastic objects should be directly proportional to the distance of deformation, regardless of how large that distance becomes. This is known as perfect elasticity, in which a given object will return to its original shape no matter how strongly it is deformed. This is an ideal concept only; most materials which possess elasticity in practice remain purely elastic only up to very small deformations, after which plastic (permanent) deformation occurs.

In engineering, the elasticity of a material is quantified by the elastic modulus such as the Young's modulus, bulk modulus or shear modulus which measure the amount of stress needed to achieve a unit of strain; a higher modulus indicates that the material is harder to deform. The material's elastic limit or yield strength is the maximum stress that can arise before the onset of plastic deformation.

Plasticity (physics):

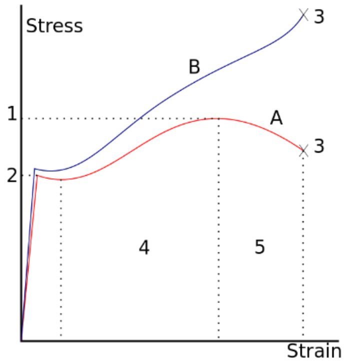
Deformation of a solid material undergoing non-reversible changes of shape in response to applied forces.

In physics and materials science, plasticity, also known as plastic deformation, is the ability of a solid material to undergo permanent deformation, a non-reversible change of shape in response to applied forces. For example, a solid piece of metal being bent or pounded into a new shape displays plasticity as permanent changes occur within the material itself. In engineering, the transition from elastic behavior to plastic behavior is known as yielding.



Stress–strain curve showing typical yield behavior for nonferrous alloys.

1. True elastic limit
2. Proportionality limit
3. Elastic limit
4. Offset yield strength



A stress–strain curve typical of structural steel.

- 1: Ultimate strength
- 2: Yield strength (yield point)
- 3: Rupture
- 4: Strain hardening region
- 5: Necking region
- A: Apparent stress (F/A0)
- B: Actual stress (F/A)

Plastic deformation is observed in most materials, particularly metals, soils, rocks, concrete, and foams. However, the physical mechanisms that cause plastic deformation can vary widely. At a crystalline scale, plasticity in metals is usually a consequence of dislocations. Such defects are relatively rare in most crystalline materials, but are numerous in some and part of their crystal structure; in such cases, plastic crystallinity can result. In brittle materials such as rock, concrete and bone, plasticity is caused predominantly by slip at microcracks. In cellular materials such as liquid foams or biological tissues, plasticity is mainly a consequence of bubble or cell rearrangements, notably T1 processes.

For many ductile metals, tensile loading applied to a sample will cause it to behave in an elastic manner. Each increment of load is accompanied by a proportional increment in extension. When the load is removed, the piece returns to its original size. However, once the load exceeds a threshold – the yield strength – the extension increases more rapidly than in the elastic region; now when the load is removed, some degree of extension will remain.

Elastic deformation, however, is an approximation and its quality depends on the time frame considered and loading speed. If, as indicated in the graph opposite, the deformation includes elastic deformation, it is also often referred to as "elasto-plastic deformation" or "elastic-plastic deformation".

Perfect plasticity is a property of materials to undergo irreversible deformation without any increase in stresses or loads. Plastic materials that have been hardened by prior deformation, such as cold forming, may need increasingly higher stresses to deform further. Generally, plastic deformation is also dependent on the deformation speed, i.e. higher stresses usually have to be applied to increase the rate of deformation. Such materials are said to deform visco-plastically."

Viscoelasticity:

Property of materials with both viscous and elastic characteristics under deformation.

In materials science and continuum mechanics, viscoelasticity is the property of materials that exhibit both viscous and elastic characteristics when undergoing deformation. Viscous materials, like water, resist shear flow and strain linearly with time when a stress is applied. Elastic materials strain when stretched and immediately return to their original state once the stress is removed.

Viscoelastic materials have elements of both of these properties and, as such, exhibit time-dependent strain. Whereas elasticity is usually the result of bond stretching along crystallographic planes in an ordered solid, viscosity is the result of the diffusion of atoms or molecules inside an amorphous material.

In the nineteenth century, physicists such as Maxwell, Boltzmann, and Kelvin researched and experimented with creep and recovery of glasses, metals, and rubbers. Viscoelasticity was further examined in the late twentieth century when synthetic polymers were engineered and used in a variety of applications. Viscoelasticity calculations depend heavily on the viscosity variable, η. The inverse of η is also known as fluidity, φ. The value of either can be derived as a function of temperature or as a given value (i.e., for a dashpot).

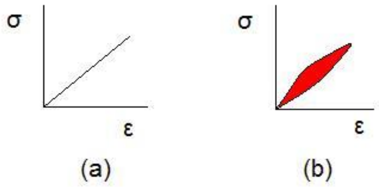
Depending on the change of strain rate versus stress inside a material, the viscosity can be categorized as having a linear, non-linear, or plastic response. When a material exhibits a linear response, it is categorized as a Newtonian material. In this case the stress is linearly proportional to the strain rate. If the material exhibits a non-linear response to the strain rate, it is categorized as non-Newtonian fluid. There is also an interesting case where the viscosity decreases as the shear/strain rate remains constant. A material which exhibits this type of behavior is known as thixotropic. In addition, when the stress is independent of this strain rate, the material exhibits plastic deformation. Many viscoelastic materials exhibit rubber like behavior explained by the thermodynamic theory of polymer elasticity.

Cracking occurs when the strain is applied quickly and outside of the elastic limit. Ligaments and tendons are viscoelastic, so the extent of the potential damage to them depends both on the rate of the change of their length as well as on the force applied.

A viscoelastic material has the following properties:

- hysteresis is seen in the stress–strain curve
- stress relaxation occurs: step constant strain causes decreasing stress
- creep occurs: step constant stress causes increasing strain
- its stiffness depends on the strain rate or the stress rate.

Elastic versus viscoelastic behavior



Stress–strain curves for a purely elastic material (a) and a viscoelastic material (b). The red area is a hysteresis loop and shows the amount of energy lost (as heat) in a loading and unloading cycle. It is equal to

$$\oint \sigma d\varepsilon$$

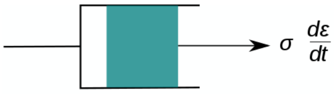
where σ is stress and ε is strain.

Unlike purely elastic substances, a viscoelastic substance has an elastic component and a viscous component. The viscosity of a viscoelastic substance gives the substance a strain rate dependence on time. Purely elastic materials do not dissipate energy (heat) when a load is applied, then removed. However, a viscoelastic substance dissipates energy when a load is applied, then removed. Hysteresis is observed in the stress–strain curve, with the area of the loop being equal to the energy lost during the loading cycle. Since viscosity is the resistance to thermally activated plastic deformation, a viscous material will lose energy through a loading cycle. Plastic deformation results in lost energy, which is uncharacteristic of a purely elastic material's reaction to a loading cycle.

Specifically, viscoelasticity is a molecular rearrangement. When a stress is applied to a viscoelastic material such as a polymer, parts of the long polymer chain change positions. This movement or rearrangement is called "creep". Polymers remain a solid material even when these parts of their chains are rearranging in order to accompany the stress, and as this occurs, it creates a back stress in the material. When the back stress is the same magnitude as the applied stress, the material no longer creeps. When the original stress is taken away, the accumulated back stresses will cause the polymer to return to its original form. The material creeps, which gives the prefix visco-, and the material fully recovers, which gives the suffix -elasticity.

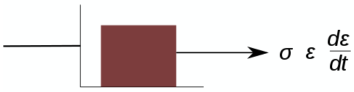
Viscoplasticity:

Viscoplasticity is a theory in continuum mechanics that describes the rate-dependent inelastic behavior of solids. Rate-dependence in this context means that the deformation of the material depends on the rate at which loads are applied. The inelastic behavior that is the subject of viscoplasticity is plastic deformation which means that the material undergoes unrecoverable deformations when a load level is reached. Rate-dependent plasticity is important for transient plasticity calculations. The main difference between rate-independent plastic and viscoplastic material models is that the latter exhibit not only permanent deformations after the application of loads but continue to undergo a creep flow as a function of time under the influence of the applied load.



(a) Dashpot Element (λ,N)

(b) Spring Element (E)



(c) Sliding Frictional Element (σy)

Figure 1. Elements used in one-dimensional models of viscoplastic materials.

The elastic response of viscoplastic materials can be represented in one-dimension by Hookean spring elements. Rate-dependence can be represented by nonlinear dashpot elements in a manner similar to viscoelasticity. Plasticity can be accounted for by adding sliding frictional elements as shown in Figure 1. In the figure E is the modulus of elasticity, λ is the viscosity parameter and N is a power-law type parameter that represents non-linear dashpot $[\sigma(d\varepsilon/dt) = \sigma = \lambda(d\varepsilon/dt)(1/N)]$. The sliding element can have a yield stress (σy) that is strain rate dependent, or even constant, as shown in Figure 1c.

Viscoplasticity is usually modeled in three-dimensions using overstress models of the Perzyna or Duvaut-Lions types. In these models, the stress is allowed to increase beyond the rate-independent yield surface upon application of a load and then allowed to relax back to the yield surface over time. The yield surface is usually assumed not to be rate-dependent in such models. An alternative approach is to add a strain rate dependence to the yield stress and use the techniques of rate independent plasticity to calculate the response of a material.

For metals and alloys, viscoplasticity is the macroscopic behavior caused by a mechanism linked to the movement of dislocations in grains, with superposed effects of inter-crystalline gliding. The mechanism usually becomes dominant at temperatures greater than approximately one third of the absolute melting temperature. However, certain alloys exhibit viscoplasticity at room temperature (300K). For polymers, wood, and bitumen, the theory of viscoplasticity is required to describe behavior beyond the limit of elasticity or viscoelasticity.

In general, viscoplasticity theories are useful in areas such as

- the calculation of permanent deformations,
- the prediction of the plastic collapse of structures,
- the investigation of stability,
- crash simulations,
- systems exposed to high temperatures such as turbines in engines, e.g. a power plant,
- dynamic problems and systems exposed to high strain rates.

Phenomenology

For a qualitative analysis, several characteristic tests are performed to describe the phenomenology of viscoplastic materials. Some examples of these tests are

1. hardening tests at constant stress or strain rate,
2. creep tests at constant force, and
3. stress relaxation at constant elongation.

Strain hardening test

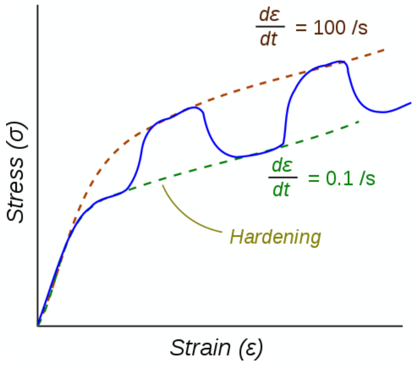


Figure 2. Stress–strain response of a viscoplastic material at different strain rates.

The dotted lines show the response if the strain-rate is held constant. The blue line shows the response when the strain rate is changed suddenly.

One consequence of yielding is that as plastic deformation proceeds, an increase in stress is required to produce additional strain. This phenomenon is known as Strain/Work hardening. For a viscoplastic material the hardening curves are not significantly different from those of rate-independent plastic material. Nevertheless, three essential differences can be observed.

1. At the same strain, the higher the rate of strain the higher the stress.
2. A change in the rate of strain during the test results in an immediate change in the stress–strain curve.
3. The concept of a plastic yield limit is no longer strictly applicable.

The hypothesis of partitioning the strains by decoupling the elastic and plastic parts is still applicable where the strains are small, i.e.,

$\varepsilon = \varepsilon e + \varepsilon vp$

where εe is the elastic strain and εvp is the viscoplastic strain.

To obtain the stress–strain behavior shown in blue in the figure, the material is initially loaded at a strain rate of 0.1/s. The strain rate is then instantaneously raised to 100/s and held constant at that value for some time. At the end of that time period the strain rate is dropped instantaneously back to 0.1/s and the cycle is continued for increasing values of strain. There is clearly a lag between the strain-rate change and the stress response. This lag is modeled quite accurately by overstress models (such as the Perzyna model) but not by models of rate-independent plasticity that have a rate-dependent yield stress."

2.2 Hysteresis and avalanches

(From Professor James Sethna, Physical Science Department of Cornell University)

Physicists in the US usually hear about hysteresis first in their sophomore or junior year. You likely won't hear about hysteresis again in your courses. It was an unpopular subject for decades.

Experimentalists generally tried to get rid of it, so they could get publishable equilibrium, data. Theorists cringed from thinking about non-equilibrium, dirty materials with long-range elastic or magnetic forces. But styles change: dirt and non-equilibrium are now a major focus of research in physics.

What's gotten us excited is the noise found in hysteresis loops. Even though they look smooth, hysteresis loops often consist of many small jumps. These jumps can be thought of as the jerk motion of a domain boundary, or as an avalanche of many local spins or domains.

Note: For a more detailed description, please refer to the "consolidated method" section which is given at the beginning of the special issue.

3. RESULTS

Figure 1 shows a stress-strain diagram in the space domain of S.FPG vs. BW during a period of 18 months From October 2020 to March 2022. This diagram has BW-1 of 1.2*BW and BW-2 of +0, +30, and -30.

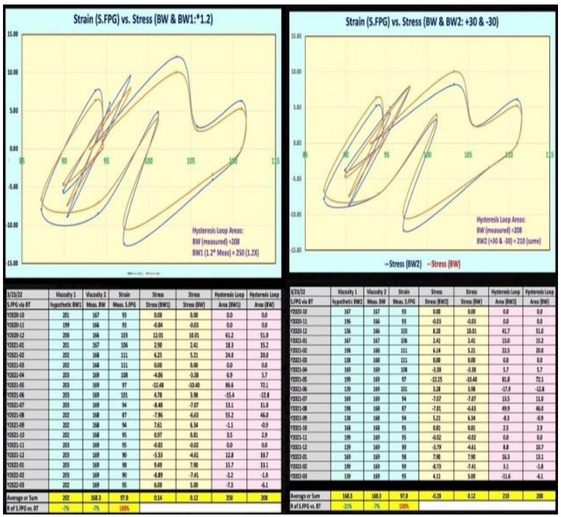


Figure 1: Stress-strain diagrams in space domain of S.FPG vs. BW during 18 months.

Figure 2 depicts a stress-strain diagram in the space domain of F.FPG vs. BW for 11 years From Y2012 to Y2022. This diagram has BW-1 of 1.2*BW and BW-2 of +0, +30, and -30.

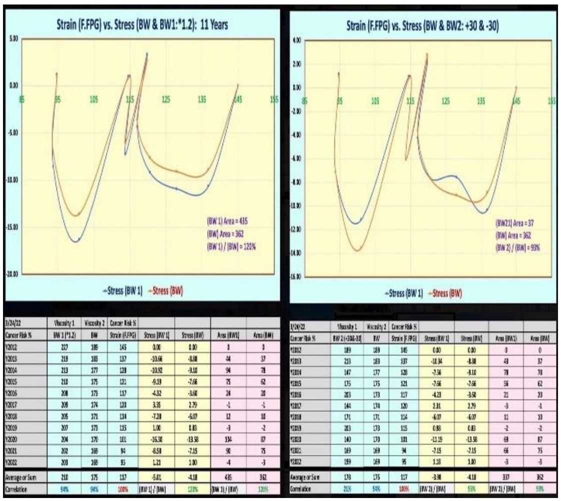


Figure 2: Stress-strain diagrams in space domain of F.FPG vs. BW during 11 years.

4. CONCLUSION

In conclusion, using the Biomedical VGT approach, he developed and learned the following important concepts:

(1) The stress or σ, i.e. influential force or cause of disease symptom ε, has two key parts. The first part is the symptom change versus time or dε/dt, i.e. symptom change rate. The change rate of symptom, strain rate, or dε/dt, not only demonstrates the importance of time-dependence characteristics of biomedical variables but also controls the stress-strain curve shape, including its vertical moving direction on the stress-strain diagram i.e., cause-symptom diagram. The second part is the influential force of the symptom, i.e. the viscosity factor or η. The viscosity factor η partially controls the magnitude of stress, i.e. magnitude of the influential force of disease symptoms. This influential force or disease cause, the viscosity factor η, further determines the range of the y-axis in the stress-strain diagram.

(2) The strain data scale of a symptom (strain or ε) determines the range of the x-axis in the stress-strain diagram and indicates the range of the symptom's fluctuations within a selected time window.

(3) The stress-strain curve (the cause-symptom curve) inside the confined rectangular space with a dimension of x-axis range and y-axis range could provide a useful indication of the maximum possible relative energy associated with the cause-symptom variance with time. This relative energy value offers a clear picture of the severity of the symptom at different time points and the estimated time requirement of developing into a certain disease (i.e., organ damages resulting from the energy). This concept and process provide a useful tool for disease prevention.

In addition, the following four numerical descriptions offer a more quantitative illustration for the above-mentioned conclusive remarks:

(1) These two stress-strain curves have different shapes and appearances which are a result of two different patterns of FPG change rates. They are further related to two different time windows of collected data (a factor having more impact) and two different glucose measurement methods (a factor having less impact). These two ranges of FPG data rates are shown on the y-axis as 20, between -10 and +10, for the 18-month sensor FPG, and 20, between -15 and +5, for the 11-year finger FPG. From a biomedical view, this strain rate, glucose change rate, is equivalent to the meaning of the existing medical terminologies: glucose fluctuation (GF) or glycemic variability (GV) which are

indicators of energy associated with glucose waves and are important elements in diabetes control.

(2) The sensor FPG of 18-months has shown a pseudo viscoelastic behavior pattern with a closed-loop. Its starting FPG is 93 mg/dL and ending FPG is 95 mg/dL due to the author's type 2 diabetes (T2D) conditions have been under control during the timeframe of 2020-2022. On the contrary, the finger FPG of 11-years has shown a viscoplastic behavior pattern with a big opening of the loop. Its starting FPG is 145 mg/dL and ending FPG is 95 mg/dL due to the author's T2D conditions continuously improving during the timeframe from Y2012 to Y2022. These two FPG data ranges are shown on the x-axis as 24, between 87 and 111, for the 18-month sensor FPG and 51, between 94 and 145, for the 11-year finger FPG.

(3) Tor to demonstrate the role and influence power of cause, i.e., viscosity factor or η, the author has created two extra datasets for "verification purposes". The first dataset, BW-1, is multiplying his measured BW by 1.2 (boosting every BW value by 20%). The second dataset, BW-2, is changing his measured BW by a sequence order of +0, +30, and -30. With this BW-2 modification, he hopes to create a "zig-zag" type or an up-and-down curve pattern. The end results from the modified BW-1 and BW-2 are(a) the hysteresis loop area of BW-1 is 20% larger than BW, and (2) the hysteresis loop area of BW-2 is almost equal to BW. These two experiments have proven that the viscosity factor η (cause of symptom) or BW, provides an enlarging or shrinking effect on the hysteresis loop area by changing its overall magnitude.

(4) The x-axis range is 24 (between 87 and 111) for the 18-month sensor FPG and 51 (between 94 and 145) for the 11-year finger FPG. The y-axis range is 20 (between -10 and +10) for the 18-month sensor FPG and 20 (between -15 and +5) for the 11-year finger FPG. Therefore, the maximum areas of two rectangular spaces are 480 (= 24*20) for the 18-month sensor FPG, and 1,020 (=51*20) for the 11-year finger FPG. The maximum rectangular area ratio is 2.13 (= 1020 / 480). However, using the trapezoid formula to calculate the real hysteresis loop areas, the two hysteresis loop areas are 208 (43% of 480) for the 18-month sensor FPG and 362 (35% of 1020) for the 11-year finger FPG. The hysteresis loop area ratio is 1.74 (= 362 / 208). From either the estimated rectangular areas or the calculated hysteresis loop areas, although the area ratios are different, we still can get a rough idea of energy generated (uploading) and dissipated (unloading) during the process of the FPG changes resulting from BW changes. This means that the longer his diabetes conditions last while being overweight, the more energy his body would carry resulting in the eventual damage to multiple internal organs. On contrary, over the past 18 months period from October/2020 to March/2022, his total energy carried inside his body resulting from FPG and BW is only 57% (= 208/362) using the hysteresis loop areas, and 47% (480/1020) using the estimated rectangular areas when compared against the past 11-years from Y2012 to Y2022. This lower energy level of 47% (using hysteresis loop area) over the past 18 months is a result of better health conditions in terms of both glucose and weight in comparison to the higher energy of 100% during the longer 11 years period which covers many earlier years with unhealthy conditions.

The above conclusions have illustrated his quantitative study results of the relationship between body weight and fasting glucose using the theories of viscoelasticity and viscoplasticity.

The relationship between obesity, diabetes, and some life-threatening complications, such as heart attacks or cancers, can be explored and investigated using certain available tools from physics and engineering. This method can even be applied to estimating the timeframe for a patient to develop certain critical diseases.

5. REFERENCES

For editing purposes, the majority of the references in this paper, which are self-references, have been removed. Only references from other authors' published sources remain. The bibliography of the author's original self-references can be viewed at www.eclairemd.com.

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Viscoelastic and Viscoplastic Glucose Theory Application in Medicine

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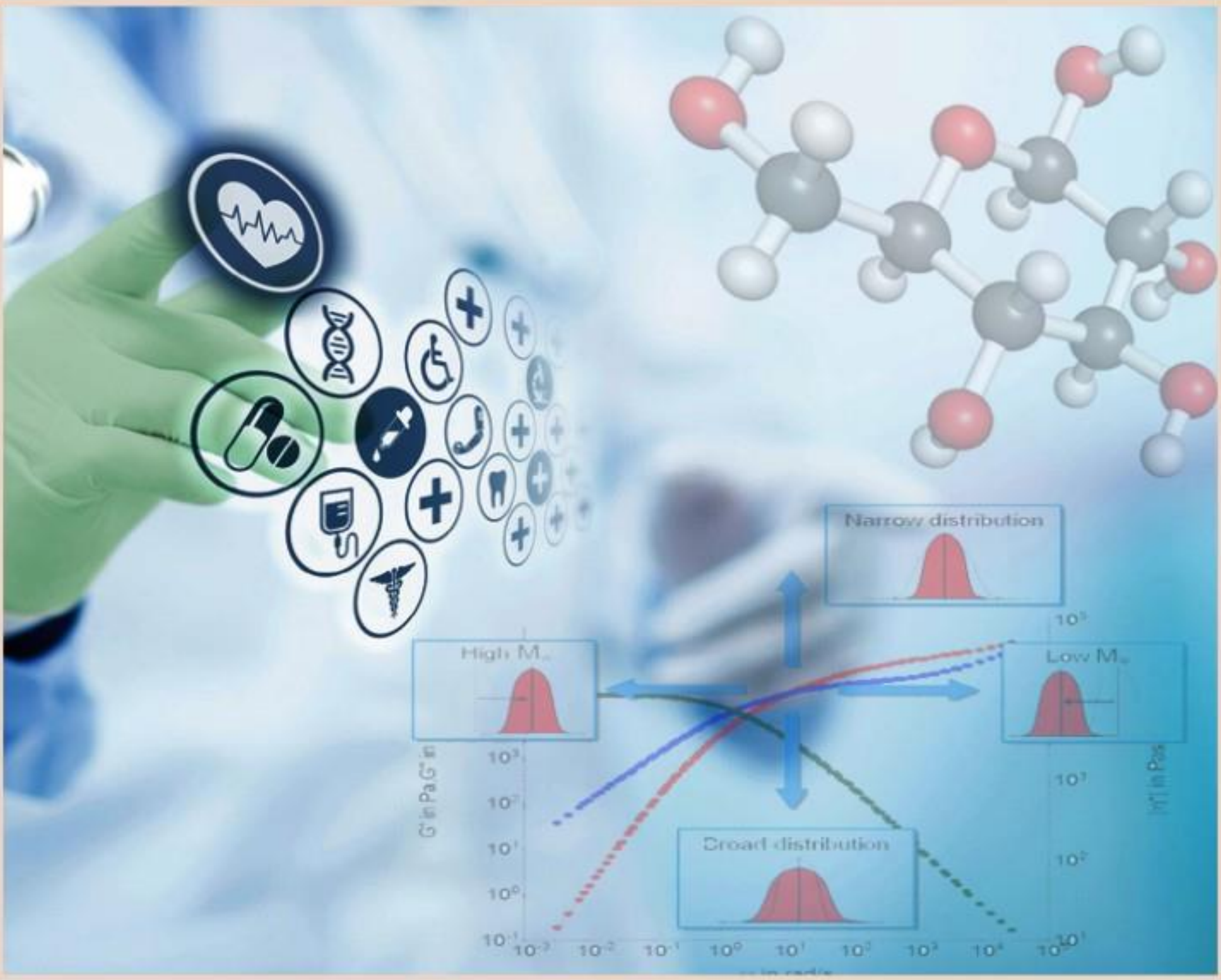

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