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(54) **Title**: METHOD FOR SIMULATING AND MEASURING LOCAL PROPERTIES OF FERROMAGNETIC ALLOYS

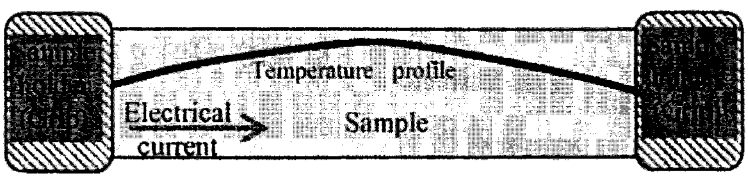

FIG. 1

(57) **Abstract**: In accordance with the present invention, disclosed herein is a method direct to determining local properties of ferromagnetic alloys and the effect of these local properties on overall mechanical performance of ferromagnetic alloys.

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METHOD FOR SIMULATING AND MEASURING LOCAL PROPERTIES OF FERROMAGNETIC ALLOYS

FIELD OF INVENTION

[0001] This disclosure relates to methods for determining local properties of ferromagnetic alloys and the effect of these local properties on overall mechanical performance of ferromagnetic alloys.

BACKGROUND

[0002] During various manufacturing operations, such as, welding, galvanizing, cold/hot rolling, and annealing, ferromagnetic alloys are subjected to different thermal cycles and/or mechanical deformations. The thermo-mechanical processing of ferromagnetic alloys can cause fluctuations of temperature and composition within localized areas of the alloys and can result in altered microstructure or stress-strain properties in these areas. These altered local microstructures or stress-strain properties can significantly affect the overall mechanical performance of the ferromagnetic alloys, or the products manufactured from these ferromagnetic alloys.

[0003] Currently available methods for determining the effects of localized microstructure on the overall mechanical performance of a ferromagnetic alloy do not allow a comprehensive analysis of such samples having a non-uniform or irregular geometry. Moreover, when conventional methods are applied to samples with a non-uniform or irregular geometry, the analysis requires an impractical number of trials to determine the effect of localized temperature and microstructural changes on the overall performance of the sample.

[0004] Accordingly, there remains a need for methods for determining the local properties of ferromagnetic alloys and the effect of these local properties on overall mechanical performance of ferromagnetic alloys. This need and other needs are satisfied by the various aspects of the present disclosure.

SUMMARY OF THE INVENTION

[0005] In accordance with the purposes of the invention, as embodied and broadly described herein, the invention relates generally to a method for simulating and measuring localized properties in a ferromagnetic alloy sample. In an aspect, the method comprises the step of providing a sample body comprised of a ferromagnetic alloy, wherein the sample body has a first sample body geometry in a first portion of the sample body and a second sample body geometry in a second portion of the sample body, wherein the first and second sample body geometry are different. A current is applied to the sample body, and at least one local property of the sample body at each of the first and the second sample body geometry is determined.

[0006] In a further aspect, the provided method can further comprise the step of measuring one or more mechanical properties of the sample body. The one or more determined local properties can comprise a local thermal property, a local microstructure, one or more local mechanical property, or any combination thereof.

[0007] In still further aspects, the sample body can be further characterized by having a longitudinal axis, wherein the first sample body geometry has a first cross sectional area along a first point of the longitudinal axis of the sample body, and the second sample body geometry has a second cross sectional area along a second point of the longitudinal axis.

[0008] Additional aspects of the invention will be set forth in part in the description which follows, and in part will be obvious from the description, or can be learned by practice of the invention. The advantages of the invention will be realized and attained by means of the elements and combinations particularly pointed out in the appended claims. It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory only and are not restrictive of the invention, as claimed.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] The accompanying figures, which are incorporated in and constitute a part of this specification, illustrate several aspects and together with the description serve to explain the principles of the invention.

[0010] **FIGURE 1** shows a schematic representation of a temperature profile along the length of the sample body determined using a thermal mechanical physical simulator.

[0011] **FIGURE 2** shows a schematic representation of a piece of the resistive material with electrical contacts on both ends.

DETAILED DESCRIPTION

[0012] The present invention can be understood more readily by reference to the following detailed description of the invention.

[0013] Before the present methods, systems, and or devices are disclosed and described, it is to be understood that the terminology used herein is for the purpose of describing particular aspects only and is not intended to be limiting. Although any methods and materials similar or equivalent to those described herein can be used in the practice or testing of the present invention, exemplary methods and materials are now described.

[0014] While aspects of the present invention can be described and claimed in a particular statutory class, such as the system statutory class, this is for convenience only and one of skill in the art will understand that each aspect of the present invention can be described and claimed in any statutory class. Unless otherwise expressly stated, it is no way intended that any method or aspect set forth herein be construed as requiring that its steps be performed in a specific order. Accordingly, where a method claim does not specifically state in the claims or descriptions that the steps are to be limited to a specific order, it is no way intended that an order be inferred, in any respect. This holds for any possible non-express basis for interpretation, including matters of logic with respect to arrangement of steps or operational flow, plain meaning derived from grammatical organization or punctuation, or the number or type of aspects described in the specification.

[0015] All publications mentioned herein are incorporated herein by reference to disclose and describe the methods and/or materials in connection with which the publications are cited.

A. DEFINITIONS

[0016] It is also to be understood that the terminology used herein is for the purpose of describing particular aspects only and is not intended to be limiting. As used in the specification and in the claims, the term "comprising" can include the aspects "consisting of" and "consisting essentially of." Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. In this specification and in the claims which follow, reference will be made to a number of terms which shall be defined herein.

[0017] As used in the specification and the appended claims, the singular forms "a," "an" and "the" include plural referents unless the context clearly dictates otherwise. Thus, for example, reference to "a sample body" can include two or more sample bodies.

[0018] As used herein, the terms "about" and "at or about" mean that the amount or value in question can be the value designated some other value approximately or about the same. It is generally understood, as used herein, that it is the nominal value indicated up to a ±10% variation unless otherwise indicated or inferred. The term is intended to convey that similar values promote equivalent results or effects recited in the claims. That is, it is understood that amounts, sizes, formulations, parameters, and other quantities and characteristics are not and need not be exact, but can be approximate and/or larger or smaller, as desired, reflecting tolerances, conversion factors, rounding off, measurement error and the like, and other factors known to those of skill in the art. In general, an amount, size, formulation, parameter or other quantity or characteristic is "about" or "approximate" whether or not expressly stated to be such. It is understood that where "about" is used before a quantitative value, the parameter also includes the specific quantitative value itself, unless specifically stated otherwise.

[0019] Ranges can be expressed herein as from "about" one particular value, and/or to "about" another particular value. When such a range is expressed, another aspect includes from the one particular value and/or to the other particular value. Similarly, when values are expressed as approximations, by use of the antecedent 'about,' it will be understood that the particular value forms another aspect. It will be further understood that the endpoints of each of the ranges are significant both in relation to the other endpoint, and independently of the other endpoint. It is also understood that there are a number of values disclosed herein, and that each value is also herein disclosed as "about" that particular value in addition to the value itself. For example, if the value "10" is disclosed, then "about 10" is also disclosed. It is also understood that each unit between two particular units are also disclosed. For example, if 10 and 15 are disclosed, then 11, 12, 13, and 14 are also disclosed.

[0020] The terms "first," "second," "first part," "second part," and the like, where used herein, do not denote any order, quantity, or importance, and are used to distinguish one element from another, unless specifically stated otherwise.

[0021] As used herein, the terms "optional" or "optionally" means that the subsequently described event or circumstance can or cannot occur, and that the description includes instances where said event or circumstance occurs and instances where it does not.

[0022] As used herein, the term or phrase "effective," "effective amount," or "conditions effective to" refers to such amount or condition that is capable of performing the function or property for which an effective amount is expressed. As will be pointed out below, the exact amount or particular condition required will vary from one aspect to another, depending on recognized variables such as the materials employed and the processing conditions observed. However, it should be understood that an appropriate effective amount will be readily determined by one of ordinary skill in the art using only routine experimentation.

[0023] As used herein, the term "local property" refers to any property of an object or a sample, whose specification is based on the behavior of the object or the sample in the relative neighborhood or region of a defined point.

[0024] As used herein, the term "microstructure" refers to a structure of a material, for example and without limitation, of a prepared ferromagnetic alloy or a product manufactured from the prepared ferromagnetic alloy as revealed by a microscope above 25X magnification. In one aspect, various thermal and mechanical processing can alter the microstructure of the material and create portions having different local microstructures within the ferromagnetic alloy. In various aspects, the microstructure, or in some aspects, the local microstructure can significantly influence physical properties of the material. In exemplary aspects, the affected physical properties include but are not limited to, a strength, toughness, ductility, hardness, corrosion resistance, high/low temperature behavior or wear resistance of the material.

[0025] As used herein, the terms "resistive heating," or "Joule heating," or "ohmic heating" can be used interchangeably and refer to a process by which the passage of an electric current through a conductor releases heat. Joule heating is independent of the direction of current. In one aspect, the amount of heat released is proportional to the square of the current according to Formula (1)

$$Q \propto I^2 \cdot R \qquad (1)$$

[0026] In one aspect, Joule heating is caused by interactions between the moving particles that form the current and the atomic ions that make up the body of the conductor. In exemplary aspects, the moving particles are electrons. The increase in the kinetic energy of the ions manifests itself as heat and a rise in the temperature of the conductor.

[0027] As used herein, the term “hardness” refers to a general property defining how resistant a solid material is to various kinds of permanent shape change when a force is applied. In one aspect, macroscopic hardness can be generally characterized by strong intermolecular bonds. In another aspect, depending on a type of force applied to the solid material, hardness can include but is not limited to scratch hardness, indentation hardness, or rebound hardness. In some aspects, hardness can depend on materials’ ductility, elastic stiffness, plasticity, strain, strength, toughness, viscoelasticity, viscosity, or a combination thereof.

[0028] As used herein, the term “thermal cycle” refers to a manufacturing process of alternatively cooling and heating material to enhance its strength and performance. In some aspects, this process can induce molecular reorganization, optimizing a material's molecular structure and making it denser and more uniform. In certain aspects, when ferromagnetic alloys are exposed to thermal cycles, a non-uniform heat distribution can cause temperature gradients in the ferromagnetic alloys, resulting in various portions of ferromagnetic alloys having different local thermal cycles.

[0029] As used herein, the term “creep” refers to the deformation of a material that occurs over time due to the presence of a constant load at elevated temperatures. The failure to hold a load over time results in “creep rupture.” In some aspects, increase in stress or temperature results in instantaneous strain increase, the steady state creep rate increase, and decrease in time to rupture.

[0030] As used herein, the term “solidification” refers to a phase transition of metal or metal alloy from a molten to solid state. In various aspects, various local microstructures can develop during solidification. In certain aspects, the local microstructures can be deepened on the solidification conditions and metal alloy composition. In certain aspect, the solidification conditions can be determined by the processing method, for example and without limitation, casting, welding, rapid solidification, and such.

[0031] As used herein, the term “reference sample body” refers to a sample body comprised of a substantially identical ferromagnetic alloy and having a substantially identical longitudinal axis, wherein the reference sample body has a substantially uniform cross sectional area along the longitudinal axis of the reference sample body such that a first and second different sample body geometry are not present in the sample.

B. METHODS

[0032] As briefly summarized above, the present disclosure provides a method for simulating one or more local properties in a ferromagnetic sample. The presence of the local property can be measured and subsequently analyzed to determine its effect on the overall performance of the sample. According to an aspect, the disclosed method comprises the step of providing a sample body comprised of a ferromagnetic alloy, wherein the sample body has a first sample body geometry in a first portion of the sample body and a second sample body geometry in a second portion of the sample body, wherein the first and second sample body geometry are different. A current can be applied to the sample body. As described further below, the application of current can initiate resistive heating which, in turn, can result in a simulated local property at each of the first and second points of differing geometry. The at least one local property of the sample body at each of the first and the second sample body geometry can then be measured or determined and subsequently analyzed.

[0033] As mentioned above, the step of applying the current to the sample body can result in resistive heating of the body. In one aspect, the current applied to the sample body comprises an electrical current. In an exemplary aspect, and as demonstrated by FIGURE 1, the electrical current applied to the sample can create a temperature profile along the length of the sample body. The electrical current can comprise direct current (DC), or alternating current (AC). In some aspects, the resistive heating can exhibit a coefficient of performance of 1.0. In these aspects, each joule of electrical energy supplied to the sample body results in one joule of heat.

[0034] In one aspect, the resistive heating can heat the sample body at rates of up to about 10,000 °C/ second, including exemplary values of about 1 °C/second, about 5 °C/second, about 10 °C/second, about 20 °C/second, about 50 °C/second, about 80 °C/second, about 100 °C/second, about 200 °C/second, about 300 °C/second, about 400 °C/second, about 500 °C/second, about 600 °C/second, about 700 °C/second, about 800 °C/second, about 900 °C/second, about 1,00^{0} °C/second, about 1,500 °C/second, about 2,000 °C/second, about 2,500 °C/second, about 3,000 °C/second, about 3,500 °C/second, about 4,000 °C/second, about 4,500 °C/second, about 5,000 °C/second, about 5,500 °C/second, about 6,000 °C/second, about 6,500

°C/second, about 7,000 °C/second, about 7,500 °C/second, about 8,000 °C/second, about 8,500 °C/second, about 9,000 °C/second, and about 9,500 °C/second. In still further aspects, the resistive heating can heat the sample body at any rate in the range of any two of the above listed exemplary values.

[0035] In another aspect, the application of current can be controlled in such a manner that the resulting resistive heating holds or maintains the sample body at steady-state equilibrium temperatures. In one aspect, the heated sample body can be cooled at high cooling rates. In some aspects, the cooling rates can reach up to 10,000 °C/second at the sample body surface.

[0036] In certain aspects, the resistive heating applied to the sample body can result in the heating of the sample body to a temperature in the range of from about 200 to about 3000 °C, including exemplary values of about 250 °C, about 300 °C, about 350 °C, about 400 °C, about 450 °C, about 500 °C, about 550 °C, about 600 °C, about 650 °C, about 700 °C, about 750 °C, about 800 °C, about 850 °C, about 900 °C, about 950 °C, about 1,000 °C, about 1,050 °C, about 1,100 °C, about 1,150 °C, about 1,200 °C, about 1,250 °C, about 1,300 °C, about 1,350 °C, about 1,400 °C, about 1,450 °C, about 1,500 °C, about 1,550 °C, about 1,600 °C, about 1,650 °C, about 1,700 °C, about 1,750 °C, about 1,800 °C, about 1,850 °C, about 1,900 °C, about 1,950 °C, about 2,000 °C, about 2,050 °C, about 2,100 °C, about 2,150 °C, about 2,200 °C, about 2,250 °C, about 2,300 °C, about 2,350 °C, about 2,400 °C, about 2,450 °C, about 2,500 °C, about 2,550 °C, about 2,600 °C, about 2,650 °C, about 2,700 °C, about 2,750 °C, about 2,800 °C, about 2,850 °C, about 2,900 °C, and about 2,950 °C. In still further aspects, the resistive heating can result in a temperature in the range of any two of the above listed exemplary values.

[0037] In certain aspects, the generation of heat Q during resistive heating can be also expressed accordingly to formula (2)

$$Q = J^2 \cdot \sigma^{-1} \qquad (2)$$

wherein J is a current density that can be determined from the formula (3)

$$J = -\sigma \nabla \varphi \quad (3),$$

wherein φ is an electrical potential that can be calculated using formula (4), commonly known as Laplace equation:

$$\nabla(\sigma\nabla\varphi) = 0 \quad (4),$$

and wherein σ is an electrical conductivity (formula 5)

$$\sigma = \frac{1}{\rho} \qquad (5),$$

wherein ρ is a resistivity that relates to a resistance accordingly to formula (6)

$$R = \rho\frac{l}{A} \quad (6),$$

wherein *l* is a length of the sample and *A* is a cross-sectional area of the sample.

[0038] Without wishing to be bound by any theory, it is believed that based on Formulas 2-6 and as demonstrated in FIGURE 2, local geometry of a sample can have a profound effect on the heat generated by application of the electrical current at the point of the localized geometry. For example and without limitation, for samples having longer and thinner sample dimensions, the resistance will be larger, which reduces the electrical conductivity and consequently the heat generated in the sample body will be increase. In further aspects, the resistance heating processes can cause a non-uniform distribution of temperature in the heated sample body (FIGURE 1). In exemplary aspects, the non-uniform distribution of temperature is along longitudinal axis of the sample bode. Thus, by providing a sample having at least a first and second point of differing sample body geometries, one or more local properties can be simulated, measured, and subsequently analyzed.

[0039] In one aspect, the temperature of the sample body during the resistive heating can be measured by thermocouples. In yet another aspect, the temperature of the sample body during the resistive heating can be measured by infrared pyrometer. When the thermocouples are used to measure the temperature of the sample body, the thermocouples can be physically attached to the sample body. In aspects where the infrared pyrometer is used to measure the sample body temperature, the infrared pyrometer is positioned to focus on the sample. In certain aspects, the infrared pyrometer is calibrated using reference thermocouples physically attached to a reference sample body having a uniform geometry. In some aspects, the thermocouples can be physically attached to the sample body or the reference body by, for example, welding.

[0040] In some aspects, wherein the current is applied to the sample having a first sample body geometry in a first portion of the sample and a second body geometry in a second portion of the sample body, the heat generated in the sample body will depend on the sample geometry.

[0041] In one aspect, the sample body has a longitudinal axis, the first sample body geometry has a first cross sectional area along a first point of the longitudinal axis of the sample body, and the second sample body geometry has a second cross sectional area along a second point of the longitudinal axis.

[0042] In one aspect, at each of the first and the second sample body geometry, the resistive heating from the application of the current results in the sample body exhibiting at least two different temperatures at each of the first and the second points along of the longitudinal axis. In some aspects, the current is applied in an amount sufficient to bring the sample body to the desirable temperature. In various aspects, the desirable temperature can be defined by one of ordinary skill in the art based on a type of the ferromagnetic alloy, and/or property to be measured.

[0043] In one aspect, the at least one local property determined at each of the first and the second sample body geometry can comprise a local thermal property, a local microstructure, a local mechanical property, or any combination thereof. In certain aspects, the at least one local property determined for each of the first and the second sample body geometry is a local thermal cycle of the sample body. In other aspects, the at least one local property determined for each of the first and the second sample body geometry is a local microstructure of the sample body. In yet other aspects, the at least one local property determined for each of the first and the second sample body geometry is a local stress/creep rupture. In yet further aspects, the at least one local property determined for each of the first and the second sample body geometry is a local melting and solidification. In some aspects, the at least one local property determined for each of the first and the second sample body geometry can be selected from one or more of a local fatigue of the sample body, a local stress relaxation of the sample body, a local compression of the sample body, or any combination thereof.

[0044] In still further aspects, the at least one local property determined for each of the first and the second sample body geometry is substantially different relative to at least one local property determined for a reference sample body having a uniform geometry.

[0045] In one aspect, the method disclosed herein can further comprise determining one or more mechanical property of the sample body. In some aspects, the step of determining the one or more mechanical property of the sample body can further comprise applying a mechanical loading to the sample body. In some aspects, the mechanical load applied to the sample body can comprise up to about 10 tons of static force in tension or compression, including exemplary values of about 10 kg, about 50 kg, about 100 kg, about 200 kg, about 400 kg, about 500 kg, about 600 kg, about 700 kg, about 800 kg, about 900 kg, about 1 ton, about 1.5 ton, about 2 ton, about 2.5 ton, about 3 ton, about 3.5 ton, about 4 ton, about 4.5 ton, about 5 ton, about 5.5 ton, about 6 ton, about 6.5 ton, about 7 ton, about 7.5 ton, about 8 ton, about 8.5 ton, about 9 ton, and about 9.5 ton. In still further aspects, the mechanical load can comprise any load in the range of any two of the above listed exemplary values.

[0046] In some aspects, when the mechanical load is applied to the sample body, displacement rates can be up to about 1,000 mm/second, including exemplary values of about 1 mm/second, about 5 mm/second, about 10 mm/second, about 20 mm/second, about 30 mm/second, about 40 mm/second, about 50 mm/second, about 60 mm/second, about 70 mm/second, about 80 mm/second, about 90 mm/second, about 100 mm/second, about 150 mm/second, about 200 mm/second, about 250 mm/second, about 300 mm/second, about 350 mm/second, about 400 mm/second, about 450 mm/second, about 500 mm/second, about 550 mm/second, about 600 mm/second, about 650 mm/second, about 700 mm/second, about 750 mm/second, about 800 mm/second, about 850 mm/second, about 900 mm/second, and about 950 mm/second. In still further aspects, the mechanical load can be applied to the sample body at displacement rates in the range of any two of the above listed exemplary values.

[0047] In certain aspects, the displacement can be measured using a linear variable differential transformer, also known as an L-gauge. In other aspects, load cells, or non-contact laser extensometry can be used to measure the displacement under the mechanical load.

[0048] In some aspects, the mechanical loading can be applied simultaneously with the application of current. In some aspects the mechanical loading is applied to the sample body that is resistive heated to a temperature of about 200 to about 3,000 °C, including exemplary values of about 250 °C, about 300 °C, about 350 °C, about 400 °C, about 450 °C, about 500 °C, about 550 °C, about 600 °C, about 650 °C, about 700 °C, about 750 °C, about 800 °C, about 850 °C, about 900 °C, about 950 °C, about 1,000 °C, about 1,050 °C, about 1,100 °C, about 1,150 °C, about 1,200 °C, about 1,250 °C, about 1,300 °C, about 1,350 °C, about 1,400

°C, about 1,450 °C, about 1,500 °C, about 1,550 °C, about 1,600 °C, about 1,650 °C, about 1,700 °C, about 1,750 °C, about 1,800 °C, about 1,850 °C, about 1,900 °C, about 1,950 °C, about 2,000 °C, about 2,050 °C, about 2,100 °C, about 2,150 °C, about 2,200 °C, about 2,250 °C, about 2,300 °C, about 2,350 °C, about 2,400 °C, about 2,450 °C, about 2,500 °C, about 2,550 °C, about 2,600 °C, about 2,650 °C, about 2,700 °C, about 2,750 °C, about 2,800 °C, about 2,850 °C, about 2900 °C, and about 2,950 °C. In still further aspects, the mechanical loading can be applied to the sample body that is resistive heated to any temperature in the range of any two of the above listed exemplary values.

[0049] In some aspects, when the mechanical loading and resistive heating are each applied to the sample body, force, temperature, and displacement can be measured to calculate one or more mechanical properties of the overall sample body. In exemplary aspects, the one or more mechanical properties of the sample body can comprise stress and strain of the ferromagnetic alloy. In other aspects, the one or more mechanical property can be selected from strain, stress, creep rupture, tensile, compression, melting, solidification, strength, ductility, dilatometry, stress relaxation and fatigue.

[0050] In certain aspects, the first sample body geometry at the first portion of the sample body is characterized by a first thickness, a first width, or a first height. The second sample geometry at the second position of the sample body can be characterized by a second thickness, a second width, or a second height, wherein the first thickness, width or height is different from the second thickness, width or height. In some aspects, the first cross-sectional area and the second cross-sectional area are different. In yet other aspects, the first sample body geometry has a first cross-sectional shape and the second sample body geometry has a second cross sectional shape, and wherein the first and the second cross-sectional shapes are different.

[0051] In some aspects, the sample body can exhibit a third or more sample body geometry in a third or more portion of the sample body, wherein the at least one local property is determined at each of the first, second and third or more body geometry where the sample body exhibits at least three or more different local temperatures when current induced resistive heating is applied. In other aspects, the sample body can exhibit a third sample body geometry having a third cross sectional area along a third point of the longitudinal axis of the sample body, and wherein the at least one local property is determined at each of the first, second and third points along of the longitudinal axis where the sample body exhibits at least three different temperatures.

[0052] In some aspects, wherein the mechanical load is applied simultaneously with applying the current to the sample body, the one or more mechanical property of the sample body is different relative to the one or more mechanical property determined for a reference sample body having a uniform geometry.

[0053] In some aspects, the ferromagnetic alloy comprises any metal or metal alloys possessing ferromagnetic properties and has high magnetic permeability. In some aspects, the ferromagnetic alloy is steel.

[0054] In certain aspects, the current applied to the sample body can be applied by any means known to one of ordinary skill in the art. In other aspects, the current is applied using a thermal mechanical physical simulator, for example and without limitation, using a conventional Gleeble® System.

[0055] In other aspects, the mechanical loading applied to the sample body can be performed by any means known to one of ordinary skill in the art. In yet other aspects, the mechanical loading is performed using a thermal mechanical physical simulator, for example and without limitation, using a conventional Gleeble® System.

[0056] In certain aspects, the method disclosed herein further comprises step of analyzing the effect of at least one determined local property on one or more mechanical properties.

[0057] In other aspects, the method disclosed herein comprises a step of analyzing the one or more determined mechanical properties of the sample body to determine one or more process conditions to use in the manufacture of a ferromagnetic alloys. In some aspects, the one or more process conditions comprise conditions effective to produce the ferromagnetic alloys exhibiting desirable local properties. In yet other aspects, the one or more process conditions comprise conditions effective to produce the ferromagnetic alloys exhibiting desirable mechanical properties. In yet further aspects, the method disclosed herein can further comprise a step of manufacturing the ferromagnetic alloy under the one or more process conditions.

C. ASPECTS

[0058] In various aspects, the present invention pertains to and includes at least the following aspects.

[0059] Aspect 1: A method comprising: a) providing a sample body comprised of a ferromagnetic alloy, wherein the sample body has a first sample body geometry in a first portion of the sample body and a second sample body geometry in a second portion of the sample body, wherein the first and second sample body geometry are different; b) applying a current to the sample body, and c) determining at least one local property of the sample body at each of the first and the second body geometry.

[0060] Aspect 2: The method of Aspect 1, further comprising step d) determining one or more mechanical property of the sample body.

[0061] Aspect 3: The method of any of one of Aspects 1-2, wherein the step of applying current to the sample body results in resistive heating of the sample body.

[0062] Aspect 4: The method of any of one of Aspects 1-3, wherein the sample body has a longitudinal axis, and wherein the first sample body geometry has a first cross sectional area along a first point of the longitudinal axis of the sample body, and the second sample body geometry has a second cross sectional area along a second point of the longitudinal axis.

[0063] Aspect 5: The method of any of one of Aspects 1-4, wherein at each of the first and the second sample body geometry, the resistive heating from the application of the current results in the sample body exhibiting at least two different temperatures at each of the first and the second sample body geometry.

[0064] Aspect 6: The method of any of one of Aspects 1-5, wherein at each of the first and the second sample body geometry, the resistive heating from the application of the current results in the sample body exhibiting at least two different temperatures at each of the first and the second points along of the longitudinal axis.

[0065] Aspect 7: The method of any of one of Aspects 1-6, wherein the at least one local property of the sample body comprises a local thermal property, a local microstructure, a local mechanical property, or any combination thereof.

[0066] Aspect 8: The method of any of one of Aspects 1-7, wherein step d) determining one or more mechanical property of the sample body further comprises applying a mechanical loading to the sample body.

[0067] Aspect 9: The method of any of one of Aspects 1-8, wherein the mechanical loading is applied simultaneously with the application of the current.

[0068] Aspect 10: The method of any of one of Aspects 1-9, wherein the first sample body geometry at the first portion of the sample body is characterized by a first thickness, a first width, or a first height, and wherein the second sample body geometry at the second portion of the sample body is characterized by a second thickness, a second width, or a second height, and wherein the first thickness, width or height is different from the second thickness, width, or height.

[0069] Aspect 11: The method of any of one of Aspects 1-10, wherein the first cross-sectional area and the second cross-sectional area are different.

[0070] Aspect 12: The method of any of one of Aspects 1-11, wherein the first sample body geometry has a first cross-sectional shape and the second sample body geometry has a second cross-sectional shape, and wherein the first and the second cross-sectional shapes are different.

[0071] Aspect 13: The method of any of one of Aspects 1-12, wherein the sample body further exhibits a third sample body geometry in a third portion of the sample body, and wherein the at least one local property is determined at each of the first, second and third sample body geometry where the sample body exhibits at least three different temperatures.

[0072] Aspect 14: The method of any of one of Aspects 1-13, wherein the sample body further exhibits a third sample body geometry having a third cross-sectional area along a third point of the longitudinal axis of the sample body, and wherein the at least one local property is determined at each of the first, second and third points along of the longitudinal axis where the sample body exhibits at least three different temperatures.

[0073] Aspect 15: The method of any of one of Aspects 1-14, wherein the at least one local property is a local thermal cycle of the sample body.

[0074] Aspect 16: The method of any of one of Aspects 1-15, wherein the at least one local property is a local microstructure of the sample body.

[0075] Aspect 17: The method of any of one of Aspects 1-16, wherein the at least one local property is a local stress/creep rupture.

[0076] Aspect 18: The method of any of one of Aspects 1-17, wherein the at least one local property is a local melting and solidification.

[0077] Aspect 19: The method of any of one of Aspects 1-18, wherein the at least one local property determined for the sample body at each of the first and the second body geometry is different relative to the at least one local property determined for a reference sample body having a uniform geometry.

[0078] Aspect 20: The method any of one of Aspects 1-19, wherein the one or more mechanical property determined for the sample body is different relative to the one or more mechanical property determined for a reference sample body having a uniform geometry.

[0079] Aspect 21: The method any of one of Aspects 1-20, wherein the one or more mechanical property selected from a group consisting of strain, stress, creep rupture, tensile, compression, melting, solidification, strength, ductility, dilatometry, stress relaxation, and fatigue.

[0080] Aspect 22: The method of any of one of Aspects 1-21, wherein the ferromagnetic alloy is steel.

[0081] Aspect 23: The method of any of one of Aspects 1-22, wherein the current is applied using a thermal mechanical physical simulator.

[0082] Aspect 24: The method any of one of Aspects 1-23, wherein the mechanical loading is performed using a thermal mechanical physical simulator.

[0083] Aspect 25: The method of any of one of Aspects 2-24, further comprising step of analyzing the effect of at least one local property determined in step c) on the one or more mechanical properties of step d).

[0084] Aspect 26: The method of any of one of Aspects 2-25, further comprising step of analyzing the one or more mechanical properties of step d) to determine one or more process conditions for use in the manufacture of a ferromagnetic alloy.

[0085] Aspect 27: The method any of one of Aspects 2-26, further comprising step of manufacturing the ferromagnetic alloy under the one or more process conditions.

[0086] Without further elaboration, it is believed that one skilled in the art can, using the description herein, utilize the present invention. The following examples are included to provide addition guidance to those skilled in the art of practicing the claimed invention. The examples provided are merely representative of the work and contribute to the teaching of the present invention. Accordingly, these examples are not intended to limit the invention in any manner.

What is claimed is:

1. A method comprising
   a) providing a sample body comprised of a ferromagnetic alloy, wherein the sample body has a first sample body geometry in a first portion of the sample body and a second sample body geometry in a second portion of the sample body, wherein the first and second sample body geometry are different;
   b) applying a current to the sample body, and
   c) determining at least one local property of the sample body at each of the first and the second body geometry.
2. The method of claim 1, further comprising step d) determining one or more mechanical property of the sample body.
3. The method of claim 1, wherein the step of applying current to the sample body results in resistive heating of the sample body.
4. The method of claim 1, wherein the sample body has a longitudinal axis, and wherein the first sample body geometry has a first cross-sectional area along a first point of the longitudinal axis of the sample body, and the second sample body geometry has a second cross-sectional area along a second point of the longitudinal axis.
5. The method of claim 1, wherein at each of the first and the second sample body geometry, the resistive heating from the application of the current results in the sample body exhibiting at least two different temperatures at each of the first and the second sample body geometry.
6. The method of claim 4, wherein at each of the first and the second sample body geometry, the resistive heating from the application of the current results in the sample body exhibiting at least two different temperatures at each of the first and the second points along of the longitudinal axis.
7. The method of claim 1, wherein the at least one local property of the sample body comprises a local thermal property, a local microstructure, or a local mechanical property.
8. The method of claim 2, wherein step d) determining one or more mechanical property of the sample body further comprises applying a mechanical loading to the sample body.
9. The method of claim 8, wherein the mechanical loading is applied simultaneously with the application of the current.

10. The method of claim 1, wherein the first sample body geometry at the first portion of the sample body is characterized by a first thickness, a first width, or a first height, and wherein the second sample body geometry at the second portion of the sample body is characterized by a second thickness, a second width, or a second height, and wherein the first thickness, width or height is different from the second thickness, width, or height.
11. The method of claim 4, wherein the first cross sectional area and the second cross sectional area are different.
12. The method of claim 1, wherein the first sample body geometry has a first cross-sectional shape and the second sample body geometry has a second cross-sectional shape, and wherein the first and the second cross-sectional shapes are different.
13. The method of claim of claim 5, wherein the sample body further exhibits a third sample body geometry in a third portion of the sample body, and wherein the at least one local property is determined at each of the first, second and third sample body geometry where the sample body exhibits at least three different temperatures.
14. The method of claim of claim 6, wherein the sample body further exhibits a third sample body geometry having a third cross-sectional area along a third point of the longitudinal axis of the sample body, and wherein the at least one local property is determined at each of the first, second and third points along of the longitudinal axis where the sample body exhibits at least three different temperatures.
15. The method of claim 1, wherein the at least one local property is a local thermal cycle of the sample body.
16. The method of claim 1, wherein the at least one local property is a local microstructure of the sample body.
17. The method of claim 1, wherein the at least one local property is a local stress/creep rupture.
18. The method of claim 1, wherein the at least one local property is a local melting and solidification.
19. The method of claim 1, wherein the at least one local property determined for the sample body at each of the first and the second body geometry is different relative to the at least one local property determined for a reference sample body having a uniform geometry.

20. The method of claim 2, wherein the one or more mechanical property determined for the sample body is different relative to the one or more mechanical property determined for a reference sample body having a uniform geometry.
21. The method of claim 2, wherein the one or more mechanical property selected from a group consisting of strain, stress, creep rupture, tensile, compression, melting, solidification, strength, ductility, dilatometry, stress relaxation, and fatigue.
22. The method of claim 1, wherein the ferromagnetic alloy is steel.
23. The method of claim 1, wherein the current is applied using a thermal mechanical physical simulator.
24. The method of claim 8 or 9, wherein the mechanical loading is performed using a thermal mechanical physical simulator.
25. The method of any of claim 2-24, further comprising step of analyzing the effect of at least one local property determined in step c) on the one or more mechanical properties of step d).
26. The method of any of claims 2-25, further comprising step of analyzing the one or more mechanical properties of step d) to determine one or more process conditions for use in the manufacture of a ferromagnetic alloy.
27. The method of claim 26, further comprising step of manufacturing the ferromagnetic alloy under the one or more process conditions.

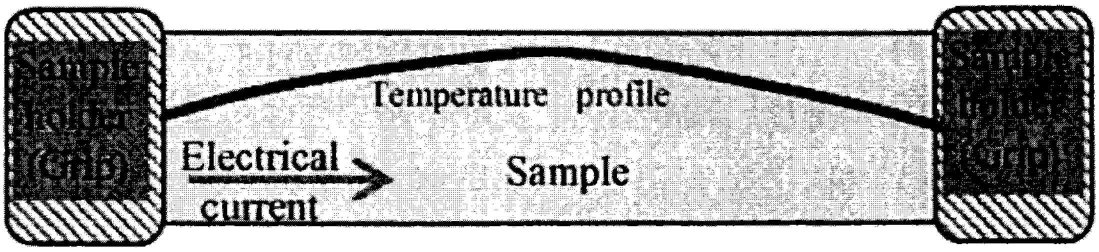
Sample holder (Grip)
Temperature profile
Electrical current
Sample

FIG. 1

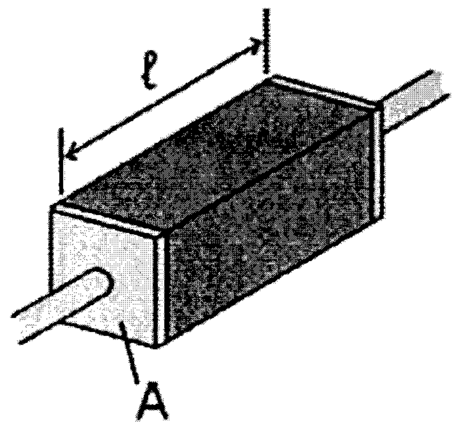

FIG. 2

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2015/001801

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01N3/60 G01N25/20 G01N33/20 H05B3/40
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G01N H05B

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 315 085 A (FERGUSON HUGO S [US]) 24 May 1994 (1994-05-24) figure 17 column 26, line 5 - column 27, line 6 column 1, line 16 - line 45 column 10, line 21 - line 35 column 2, line 40 - line 56 column 11, line 6 - line 43 column 6, line 54 - line 68 -----	1-27
A	WO 2007/093018 A2 (UNIV LOUVAIN [BE]; PARDOEN THOMAS [BE]; FABREGUE DAMIEN [FR]; RASKIN J) 23 August 2007 (2007-08-23) page 12, line 13 - line 22; figure 6 -----	1-27
	-/--	

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
9 December 2015	16/12/2015

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Schrauwen, Annelore

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 512 727 A (MYERS JEFFREY L [US] ET AL) 30 April 1996 (1996-04-30) figure 3 figure 1 abstract -----	1-27

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/IB2015/001801

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5315085 A	24-05-1994	US 5315085 A	24-05-1994
		WO 9414046 A2	23-06-1994
WO 2007093018 A2	23-08-2007	CA 2641606 A1	23-08-2007
		CA 2678071 A1	21-08-2008
		EP 1987336 A2	05-11-2008
		JP 2009526972 A	23-07-2009
		US 2010057381 A1	04-03-2010
		US 2010224006 A1	09-09-2010
		WO 2007093018 A2	23-08-2007
US 5512727 A	30-04-1996	NONE	