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(54) ELEVATED TEMPERATURE FORMING METHODS FOR METALLIC MATERIALS

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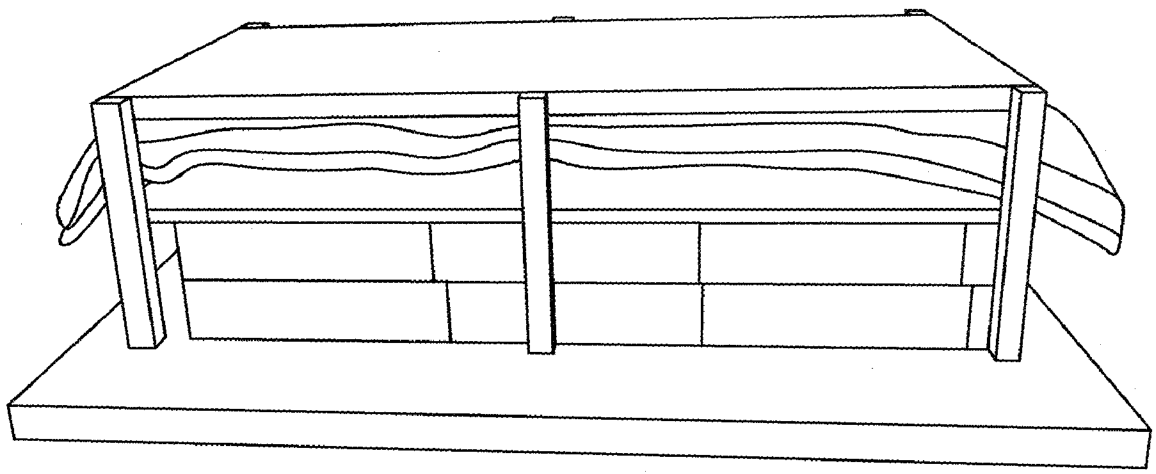
(57) **ABSTRACT**

A method of forming a metallic article includes directly and/or indirectly inductively heating a localized region of a metallic article to a forming temperature. The metallic article may comprise materials selected from titanium alloys, nickel-base alloys, and specialty steels, e.g., stainless steel, high-strength low-alloy steel, armor steel alloys, and the like. The forming temperature may be in a forming temperature range of 0.2 to 0.5 of a melting temperature of a metallic material comprising the article. The metallic article is formed in the localized region. Devices for indirectly and directly inductively heating a localized region of a metallic article are disclosed. Articles including metallic articles processed according to the methods and/or devices taught herein also are disclosed.



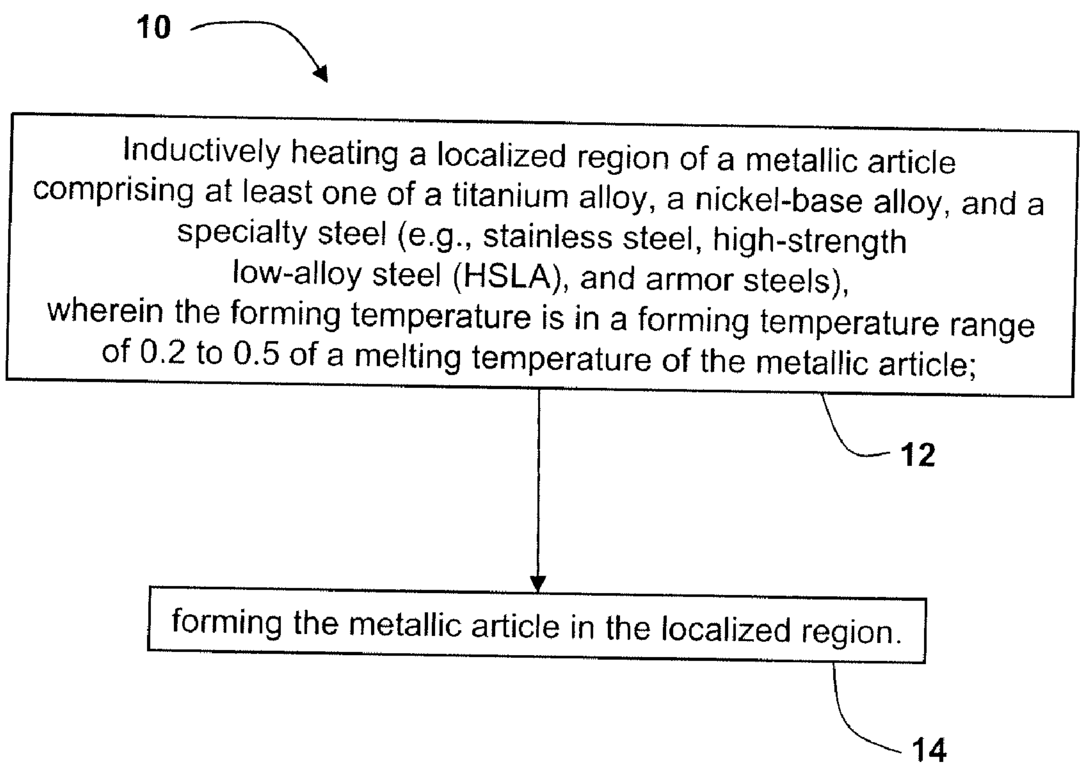

10
Inductively heating a localized region of a metallic article comprising at least one of a titanium alloy, a nickel-base alloy, and a specialty steel (e.g., stainless steel, high-strength low-alloy steel (HSLA), and armor steels), wherein the forming temperature is in a forming temperature range of 0.2 to 0.5 of a melting temperature of the metallic article;
12
forming the metallic article in the localized region.
14

FIG. 1

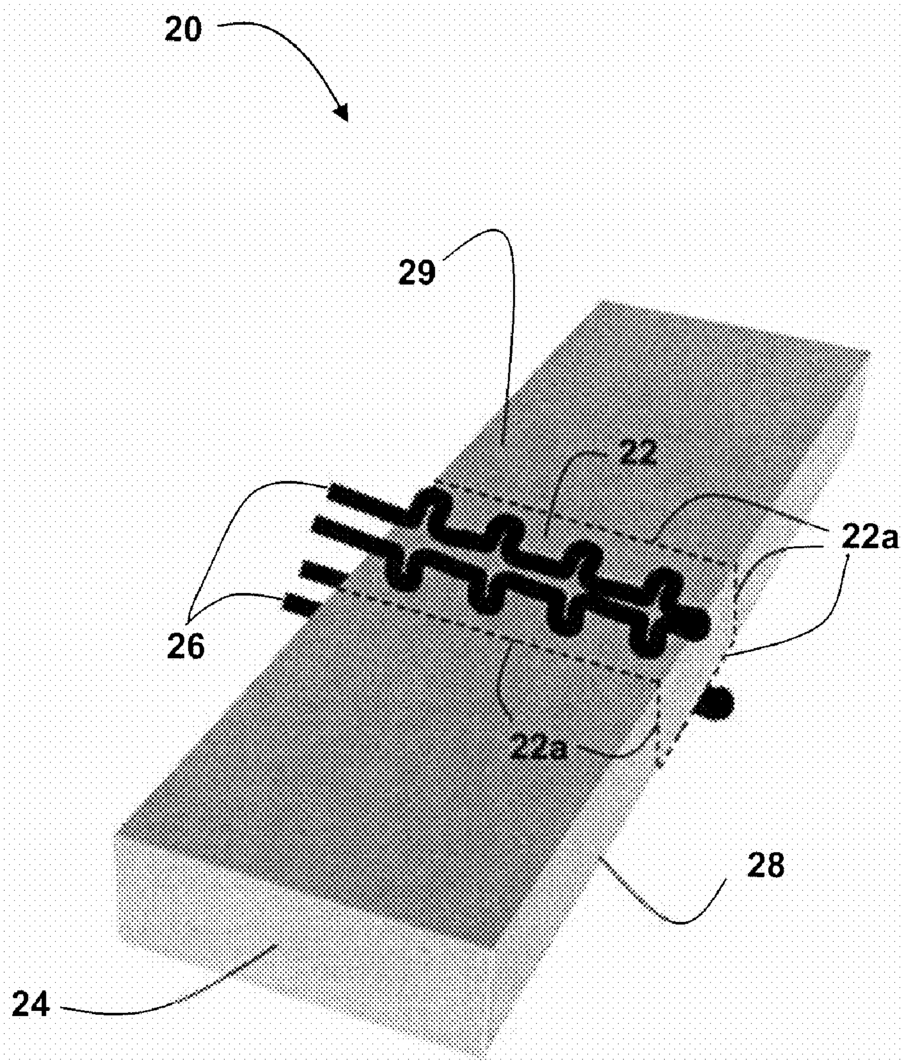


FIG. 2

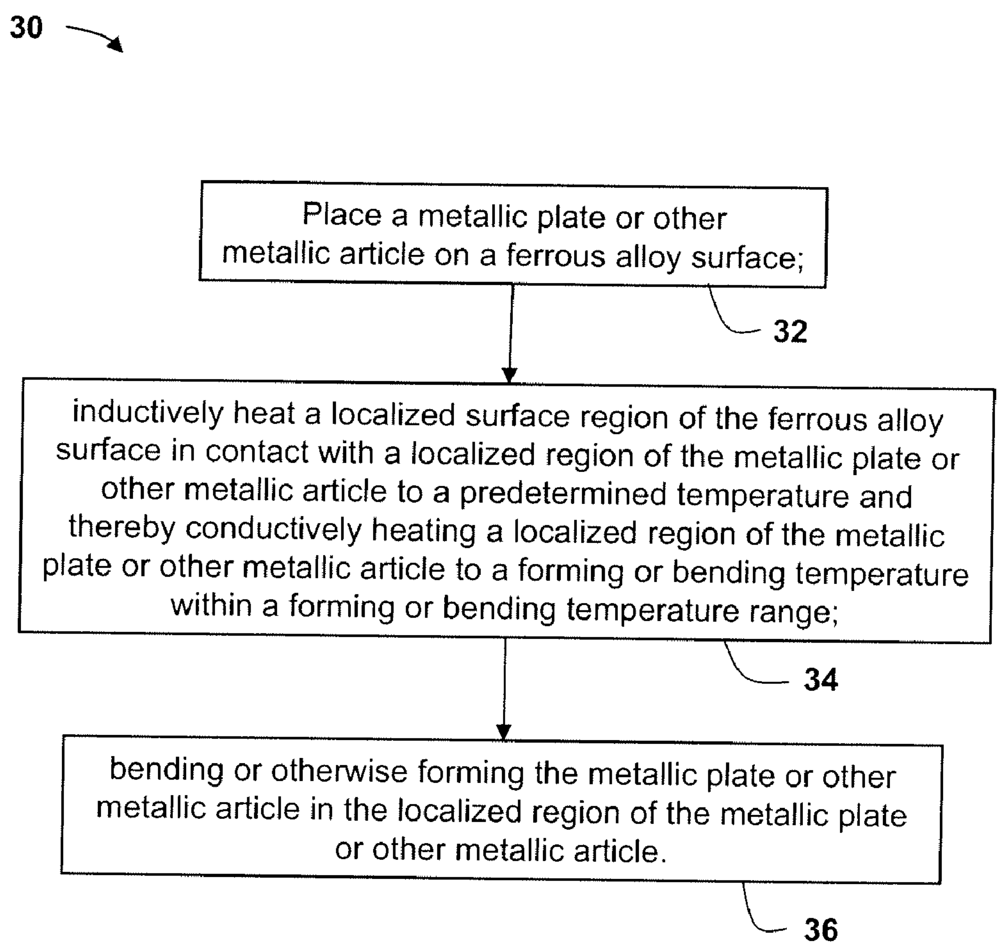

30
Place a metallic plate or other metallic article on a ferrous alloy surface;
32
inductively heat a localized surface region of the ferrous alloy surface in contact with a localized region of the metallic plate or other metallic article to a predetermined temperature and thereby conductively heating a localized region of the metallic plate or other metallic article to a forming or bending temperature within a forming or bending temperature range;
34
bending or otherwise forming the metallic plate or other metallic article in the localized region of the metallic plate or other metallic article.
36

FIG. 3

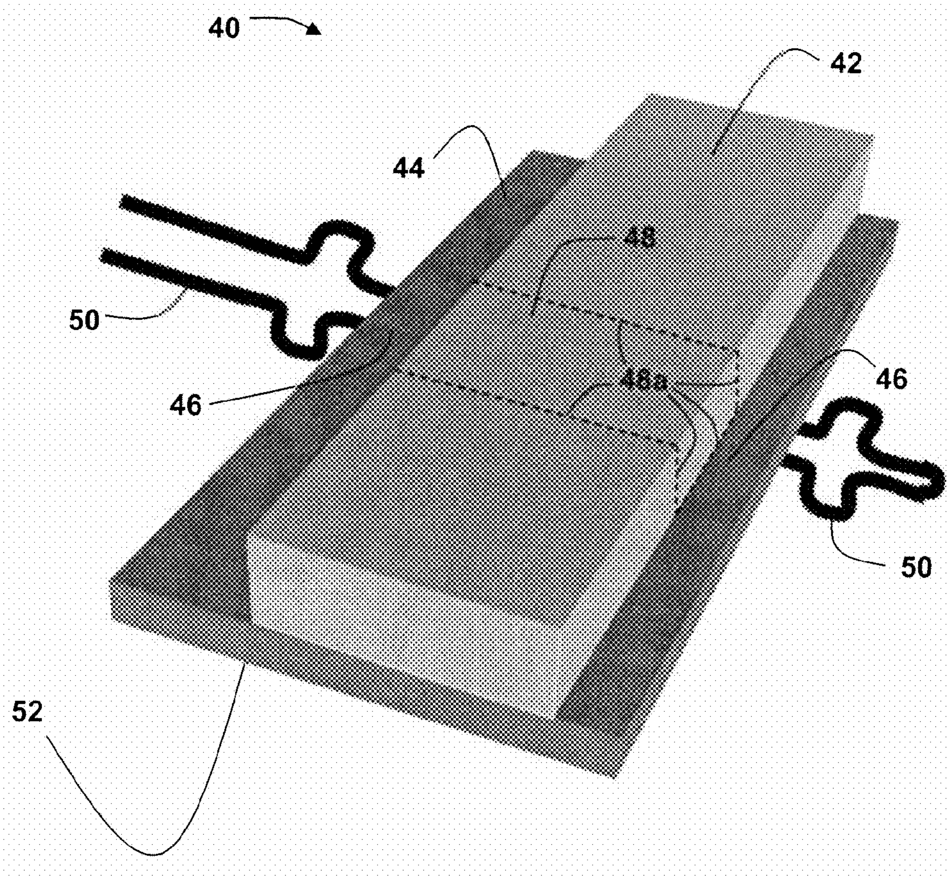


FIG. 4

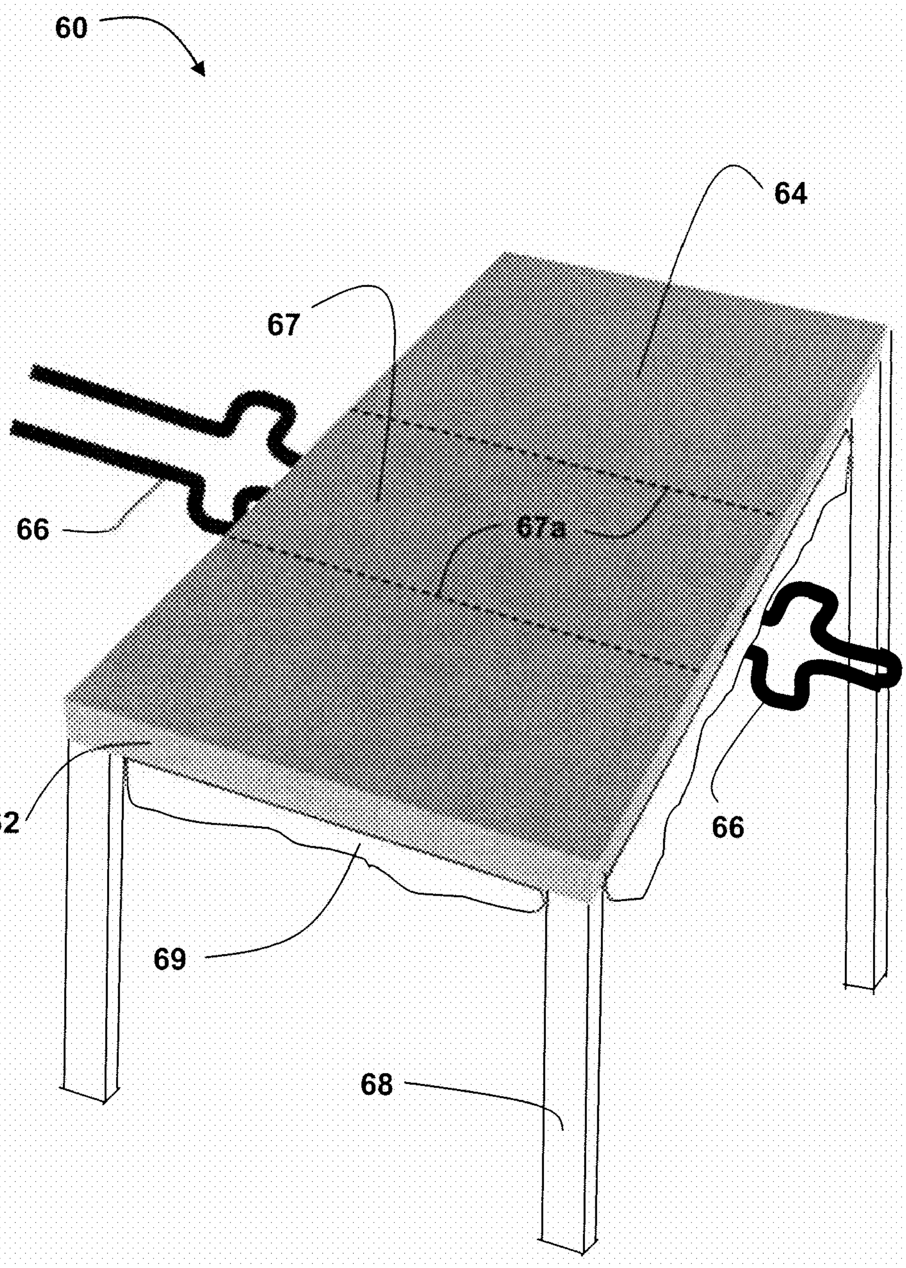


FIG. 5

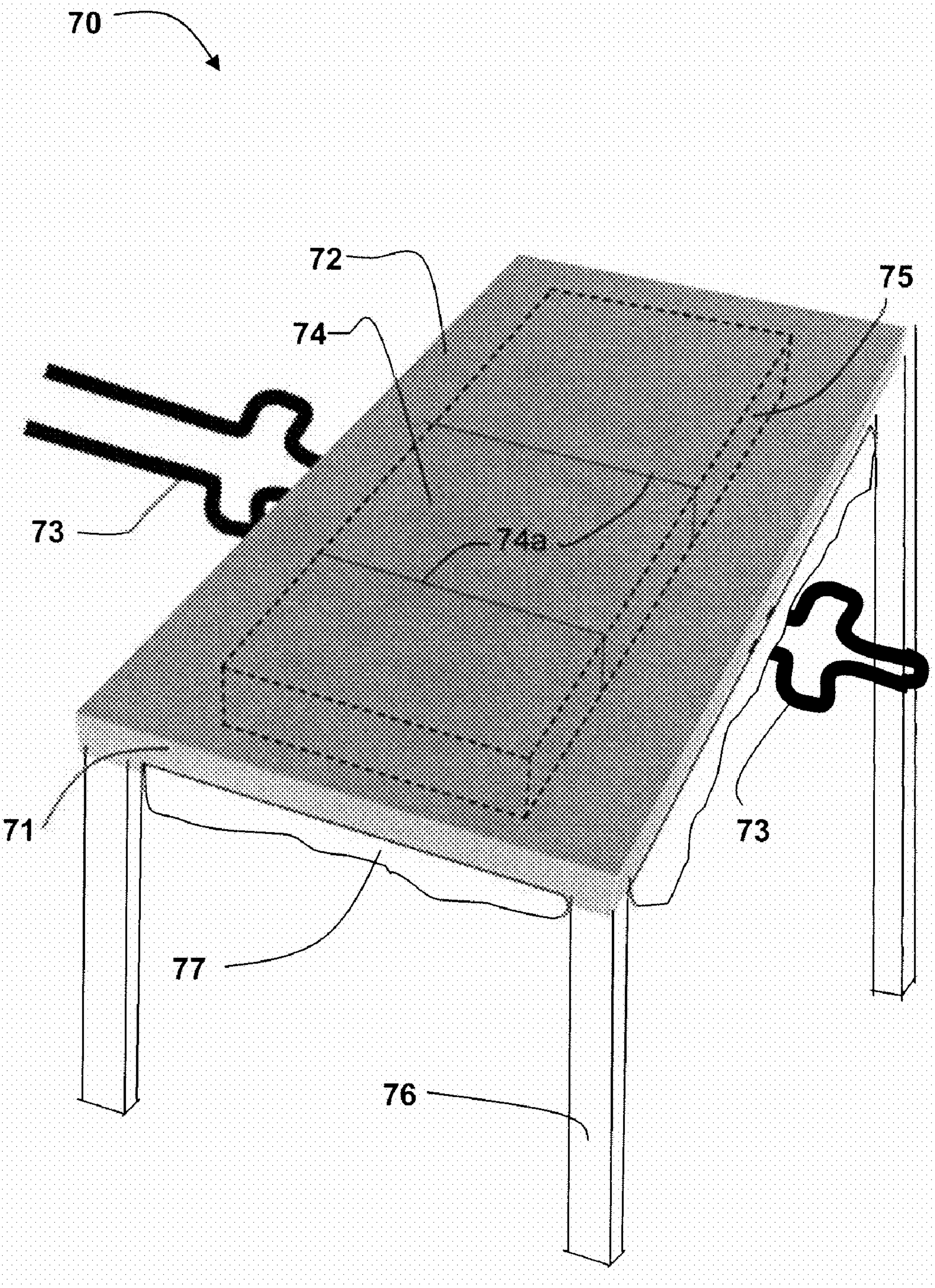


FIG. 6

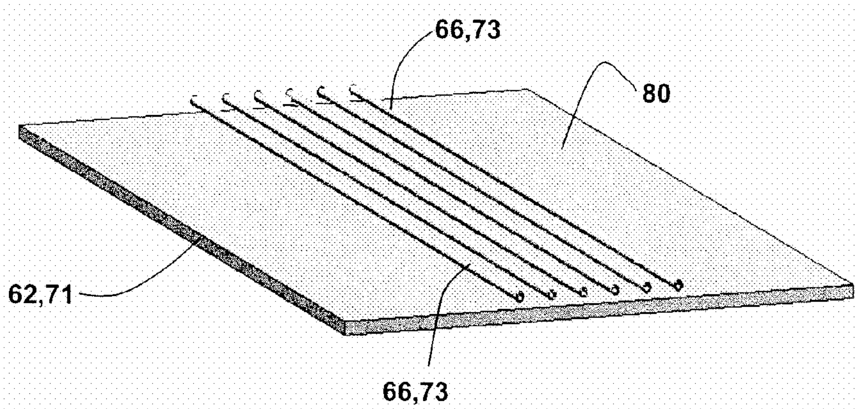


FIG. 7a

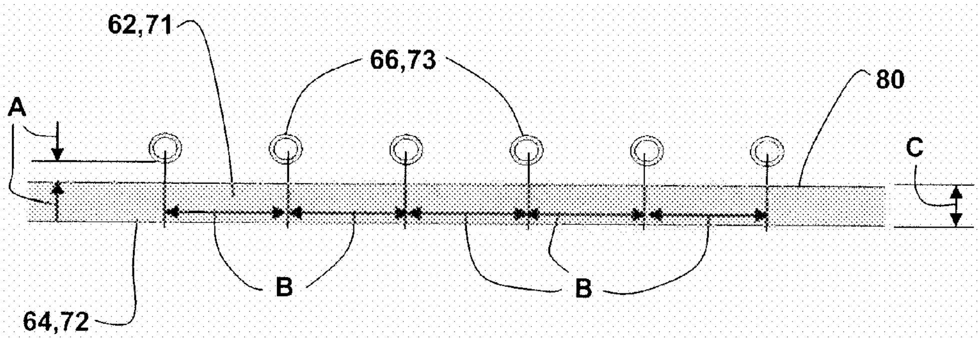


FIG. 7b

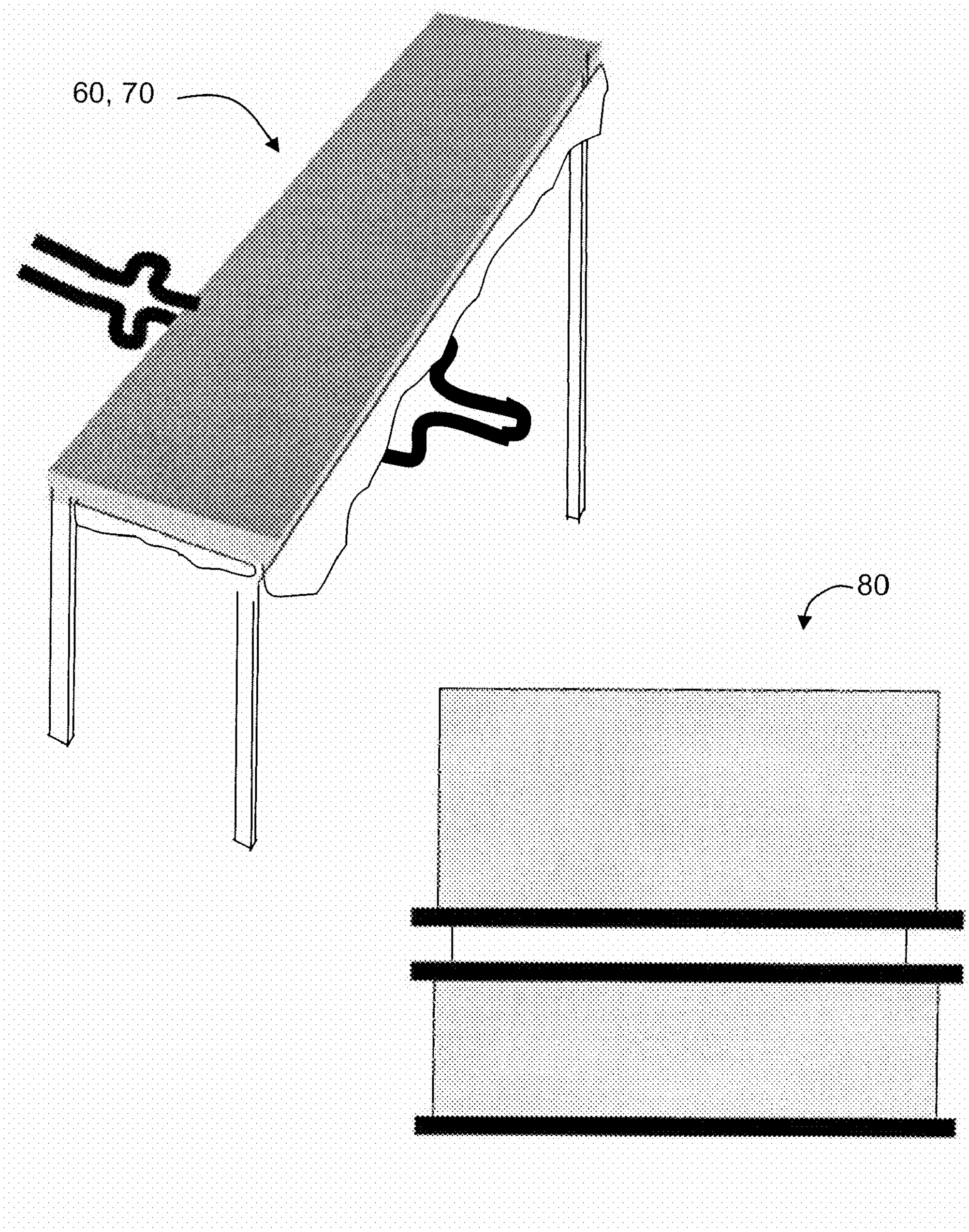


FIG. 8

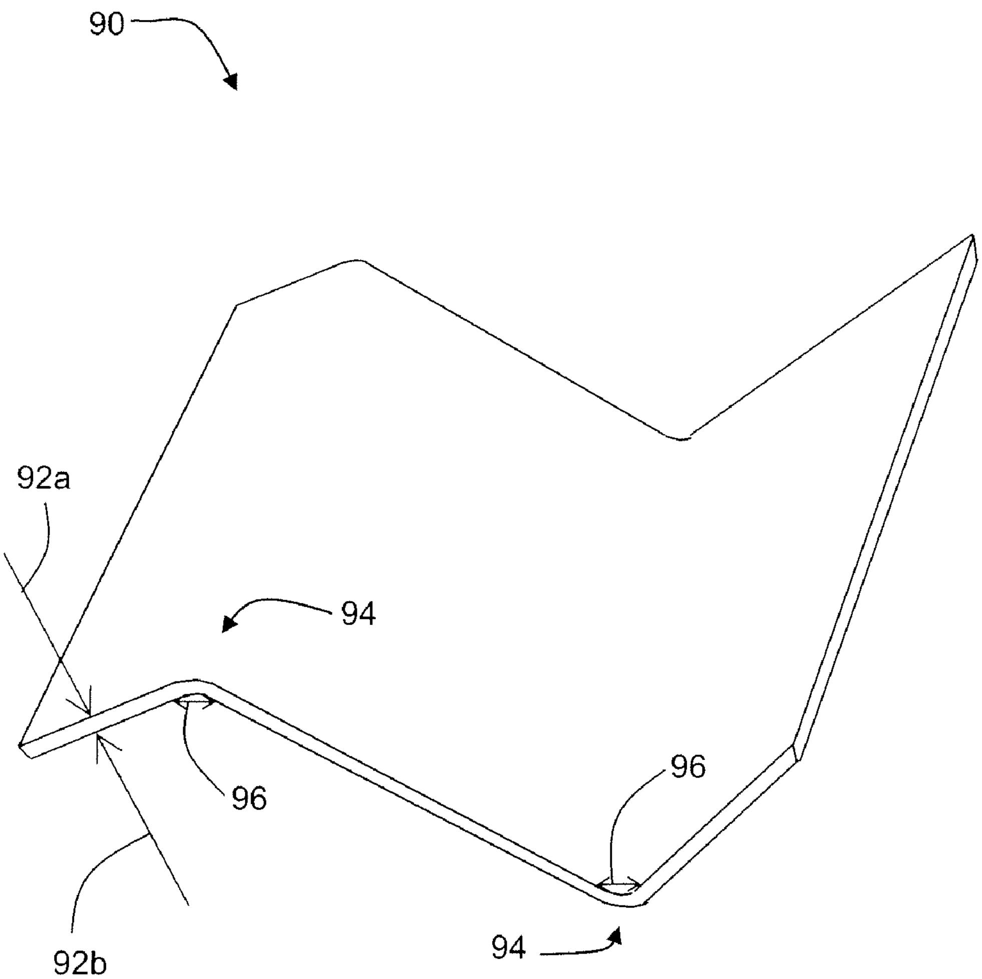


FIG. 9

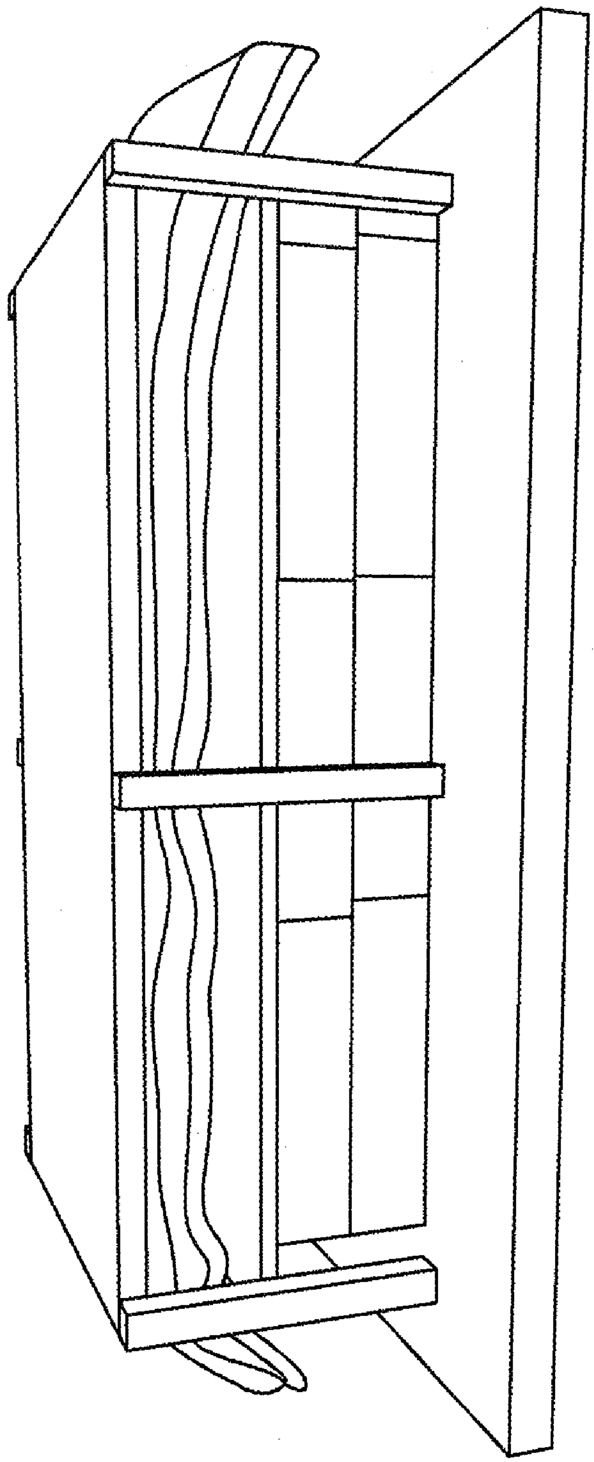


FIG. 10

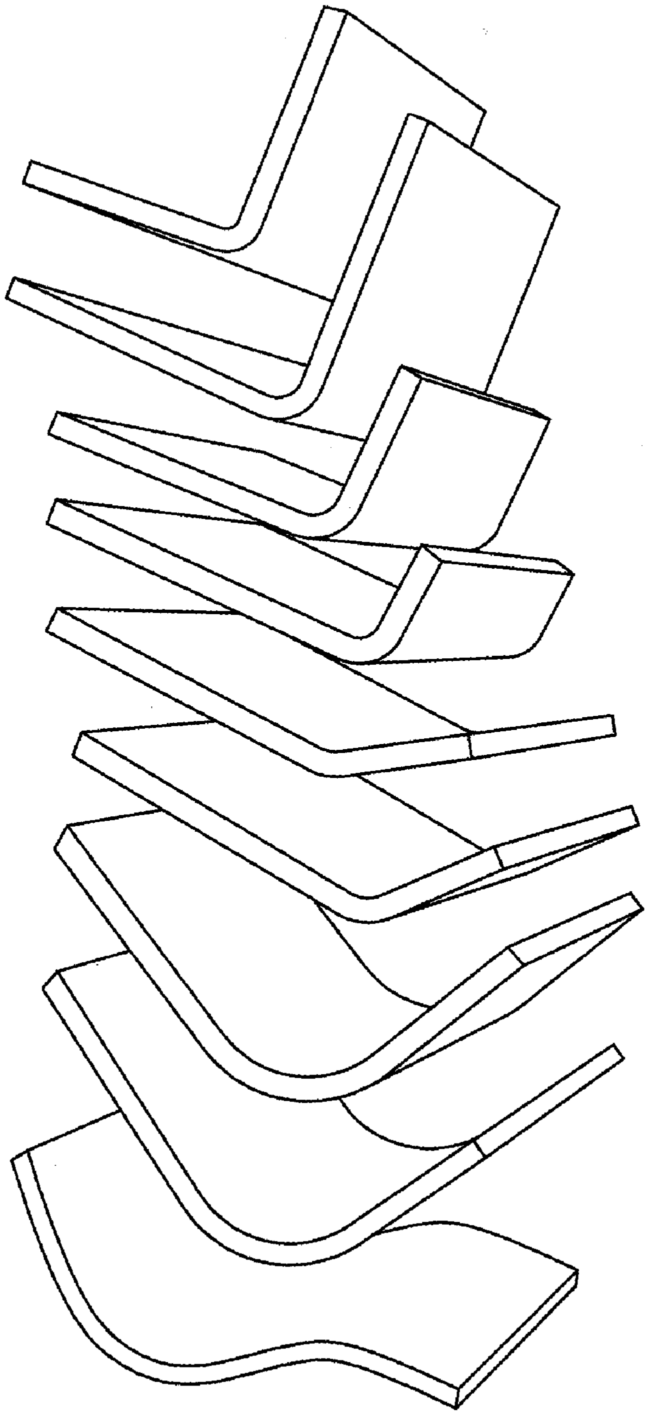


FIG. 11

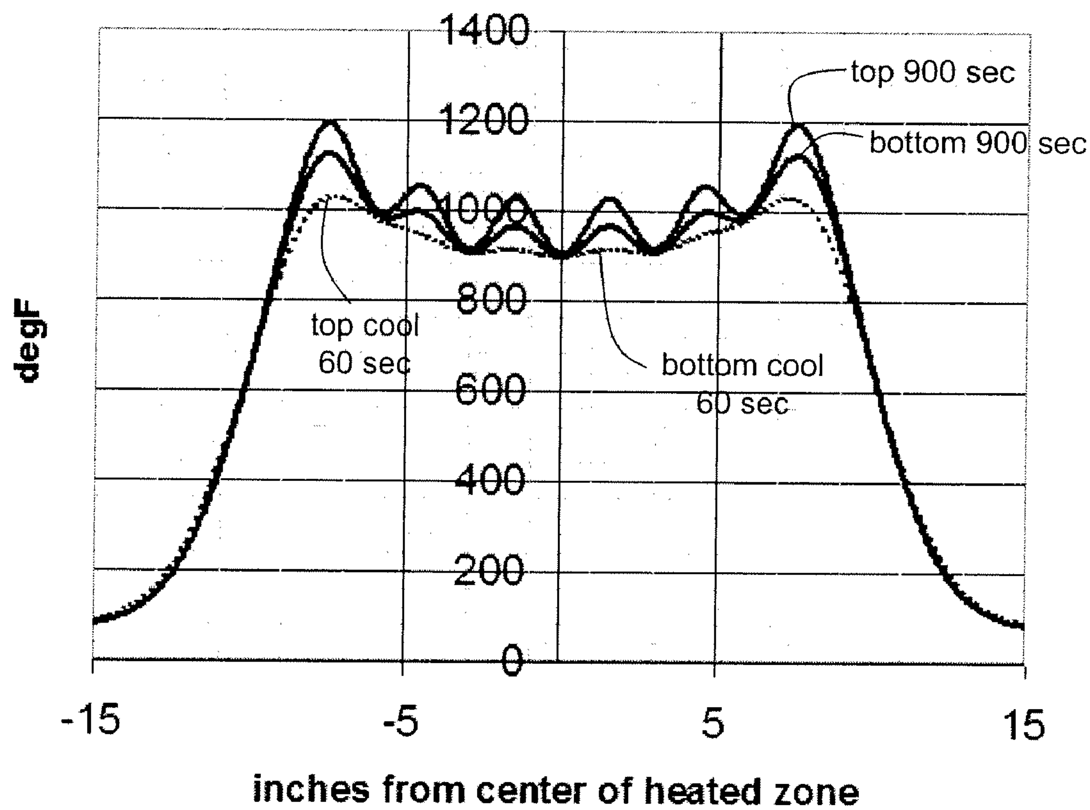

1400
1200
1000
800
600
400
200
0
degF
top 900 sec
bottom 900 sec
top cool
60 sec
bottom cool
60 sec
-15
-5
5
15
inches from center of heated zone

FIG. 12

ELEVATED TEMPERATURE FORMING METHODS FOR METALLIC MATERIALS

BACKGROUND OF THE TECHNOLOGY

[0001] 1. Field of the Technology

[0002] The present disclosure is directed to methods of forming hard-to-form metallic materials, i.e., metals and metal alloys, using localized direct or indirect induction heating.

[0003] 2. Description of the Background of the Technology

[0004] It is generally known that certain metals and metal alloys, including, for example, titanium, titanium alloys, nickel-base alloys, and specialty steels (e.g., stainless steel, high-strength low-alloy steel (HSLA), armor steel alloys, and the like), are difficult to form. Such metallic materials are generally referred to herein as "hard-to-form" metallic materials. Hard-to-form metallic materials are generally more difficult to form as their thickness, width, and/or length increase. Many hard-to-form metallic materials cannot be effectively and efficiently formed into desired shapes or components without the use of an extensive and costly set of processing steps. Conventional techniques of making parts from hard-to-form metallic materials may include: welding together multiple pieces; machining or hogging out whole sections to provide desired shapes; and advanced forming techniques, such as net shape casting, forging, super-plastic forming, and the like. Many conventional part making techniques have limitations due to degradation of metal properties that exclude the techniques from use with hard-to-form metallic materials. For example, a heat affected zone my result from welding, and machining and casting defects may exist that are not readily detectable. Conventional forming of hard-to-form metallic materials normally involves significant post-forming operations for surface repair, flatness control, dimensional stability, cosmetic repair, and adjustment/recovery of desired mechanical properties.

[0005] Fabricators have employed direct heating of hard-to-form metals and metal alloys with classic open torch technology, such as rose-bud torch technology. These methods, however, have met with only mixed success and generally are less successful as the size of the component or part increases. Poor temperature control and poor uniformity of heating is a common drawback of such methods. The use of open torch technology to heat a bend region of alpha+beta titanium alloy plate, for example, can produce undesirable phase transformations due to poor temperature control, resulting in beta phase at the surface of the plate, with an increasing concentration of alpha+beta phase microstructure moving toward the plate centerline.

[0006] Other known methods for bending hard-to-form metallic materials generally involve high temperature heating prior to and/or during forming. Such processes may require multiple heating steps to enable forming of a part. In addition, high temperature forming usually requires post-forming operations such as annealing, surface conditioning, pickling, dimensional stabilization, and/or additional rework. Also, such high temperature work can require a large furnace, depending on part size and dimensions of the formed component. Logistics, feasibility, and expense may render such processing impractical from an operational, scheduling, and cost perspective.

[0007] Attempts have been made to develop improved techniques for forming of hard-to-form metallic materials. For example, U.S. Pat. No. 6,071,360 discloses a method for superplastic forming of thick titanium alloy plate. The plate is heated to superplastic temperatures, e.g., 1650° F. (898.9° C.), and forming takes place using a press ram. Completion of a part is accomplished by machining the formed plate. The '360 patent states that a 7.87 inch (20 cm) thick plate can be bent to about 130° with a 5 inch (12.7 cm) to 6 inch (15.24 cm) inner radius bend. In an embodiment of the '360 patent, a 2 inch (5.08 cm) thick plate was formed with a complex curvature exceeding a 12 inch (30.48 cm) depth over an area of 30×60 inches (76.2.×152.4 cm). One drawback of the method described in the '360 patent is the high temperature and specialized equipment required to achieve superplasticity in the alloy plate.

[0008] In light of the above discussion, there is a need for improved methods to bend and otherwise form hard-to-form metallic materials.

SUMMARY

[0009] According to one aspect of the present disclosure, a method of forming a metallic article comprises inductively heating a localized region of a metallic article to a forming temperature. In a non-limiting embodiment, the forming temperature is in a forming temperature range of 0.20 to 0.50 of a melting temperature of the material from which the metallic article is comprised. After inductively heating the localized region, the metallic article is formed in the localized region. In non-limiting embodiments, forming the metallic article comprises at least one of bending, drawing, punching, stamping, and roll forming the metallic article. In certain non-limiting embodiments, the metallic article comprises a material selected from a titanium alloy, a nickel-base alloy, a stainless steel alloy, a high-strength low-alloy steel, and an armor steel alloy.

[0010] According to another aspect of the present disclosure, a method of bending a metallic plate includes inductively heating a lineal region of the metallic plate to a bending temperature. In a non-limiting embodiment, the bending temperature is in a bending temperature range of 0.2 to 0.5 of a melting temperature of the metallic material from which the metallic plate is comprised. After inductively heating the lineal region of the metallic plate, the plate is bent along (i.e., in) the lineal region. In non-limiting embodiments, the metallic material from which the metallic plate is comprised is a material selected from a titanium alloy, a nickel-base alloy, a stainless steel alloy, a high-strength low-alloy steel and an armor steel alloy.

[0011] According to yet another aspect of the present disclosure, a method of forming a metallic material includes placing a metallic article comprising a material selected from a metal and a metal alloy on a ferrous alloy surface. The ferrous alloy surface is inductively heated to a predetermined temperature in a localized region of the ferrous alloy surface that is in contact with a localized region of the metallic article, and the localized region of the metallic article is thereby conductively heated to a forming temperature within a forming temperature range. The metallic article is formed in the localized region. In non-limiting embodiments, the metallic article comprises a metallic material selected from a titanium alloy, a nickel-base alloy, a stainless steel alloy, a high-strength low-alloy steel, and an armor steel alloy. In another non-limiting embodiment, the forming temperature range is 0.2 to 0.5 of a melting temperature of the metallic material.

[0012] According to a further aspect of the present disclosure, a method of bending a metallic plate includes placing a

metallic plate comprising a metallic material selected from a metal and a metal alloy on a ferrous alloy surface. A lineal region of the ferrous alloy surface in contact with a lineal region of the plate is inductively heated to a predetermined temperature, and a lineal region of the metallic plate is thereby conductively heated to a bending temperature within a bending temperature range. The metallic plate is bent in the lineal region of the metallic plate. In a non-limiting embodiment, the bending temperature range is 0.2 to 0.5 of a melting temperature of the metallic material. In other non-limiting embodiments, the metallic plate comprises a metallic material selected from a titanium alloy, a nickel-base alloy, a stainless steel alloy, a high-strength low-alloy steel, and an armor steel alloy.

[0013] According to yet a further aspect of the present disclosure, a device for indirect localized heating of a metallic article including a material selected from a metal and a metal alloy comprises a support that includes a ferrous alloy surface, and at least one induction heating device. The at least one induction heating device is positioned and adapted to inductively heat a localized region of the ferrous alloy surface. The inductively heated localized region of the ferrous alloy surface is adapted to heat a localized region of a metallic article that is positioned on the ferrous alloy surface to a predetermined temperature.

[0014] According to still another aspect of the present disclosure, a device for direct localized heating of a metallic article including a material selected from a metal and a metal alloy comprises a support including a support surface. At least one induction heating device is positioned and adapted to inductively heat a localized region of the metallic article positioned on the support surface to a predetermined temperature. The support and the support surface comprise a material that is not inductively heated by the at least one induction heating device.

[0015] An additional aspect of the present disclosure is directed to a system for bending a metallic article comprising a material selected from a metal and a metal alloy. The system includes a support including a ferrous alloy surface, and at least one induction heating device. The at least one induction heating device is positioned and adapted to inductively heat a predetermined lineal region of the ferrous alloy surface. The inductively heated lineal region of the ferrous alloy surface is adapted to conductively heat a lineal region of a metallic article positioned on the ferrous alloy surface to a bending temperature in a bending temperature range. The system further includes a metallic material bending apparatus positioned proximate the ferrous alloy surface and adapted to bend the metallic article along the lineal region before the lineal region cools below the bending temperature range.

[0016] Another aspect of the present disclosure is directed to a formed ballistic armor plate comprising a metallic material selected from a titanium alloy, a nickel-base alloy, a stainless steel alloy, a high-strength low-alloy steel, and an armor steel alloy, and wherein the plate has at least one bend region having a bend radius of at least 2 t. The formed ballistic plate may be provided as, for example, a monolithic hull, a V-shaped hull, a blast protective vehicle underbelly, or an enclosure.

[0017] A further aspect of the present disclosure is directed to an article of manufacture including a formed ballistic armor plate according to the present disclosure. The formed ballistic plate may be in the form of, for example, a monolithic hull, a V-shaped hull, a blast protective vehicle underbelly, or an enclosure. In certain embodiments, the formed ballistic plate may include one of a titanium alloy, a nickel-base alloy, a stainless steel alloy, a high-strength low-alloy steel, and an armor steel alloy, and may include at least one bend region having a bend radius of at least 2 t.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] The features and advantages of certain non-limiting embodiments described herein may be better understood by reference to the accompanying drawings in which:

[0019] FIG. **1** is a flow diagram of a non-limiting embodiment according to the present disclosure of a method for forming an article comprising a hard-to form metallic material;

[0020] FIG. **2** is a schematic representation of a non-limiting embodiment according to the present disclosure of a method including inductively heating a lineal region of a plate or sheet of a hard-to-form metallic material;

[0021] FIG. **3** is a flow diagram of a non-limiting embodiment according to the present disclosure of a method for bending or otherwise forming a plate, sheet, or other article of a hard-to-form metallic material;

[0022] FIG. **4** is a schematic representation of a non-limiting embodiment according to the present disclosure of a method utilizing indirect induction heating to indirectly heat a lineal or other localized region of a hard-to-form metallic plate, sheet, or other article in order to form the metallic article;

[0023] FIG. **5** is a schematic representation of a non-limiting embodiment of a device including a support comprising a ferrous alloy surface, and at least one induction heater. The at least one induction heater is positioned and adapted to inductively heat a localized region of the ferrous alloy surface in a substantially uniform manner to thereby conductively heat a localized region of a metallic article in a substantially uniform manner;

[0024] FIG. **6** is a schematic representation of a non-limiting embodiment of a device including a support and at least one induction heater. The at least one induction heater is positioned and adapted to inductively heat a localized region of a metallic article positioned on the surface of the support in a substantially uniform manner. The support comprises material that is not inductively heated by the at least one induction heater;

[0025] FIGS. **7***a* and **7***b* depict schematic representations of a non-limiting embodiment of a support for a device for direct and indirect induction heating of a localized region of a metallic article;

[0026] FIG. **8** depicts a non-limiting embodiment of a system for forming a metallic article, wherein the device includes an induction heating device adapted to heat a localized region of a metallic article, and a forming apparatus situated near the induction heating device to enable forming of the metallic article before the temperature of the localized region of the metallic article cools below a forming temperature range;

[0027] FIG. **9** is a schematic representation of a non-limiting embodiment according the present disclosure of a formed ballistic armor plate having at least one bend radius of about 2 t;

[0028] FIG. **10** is a photograph of a non-limiting embodiment of a heating device according to the present disclosure, in the form of a heating table;

[0029] FIG. **11** is a photograph of 1-inch (2.54 cm) thick ATI 425 titanium alloy (Ti-4Al-2.5V-1.5Fe-0.25)$_2$ (UNS R54250)) plate samples bent to increasing radii of 1 t through 6 t using a non-limiting embodiment of a method according to the present disclosure; and

[0030] FIG. **12** is a plot of temperatures within a localized region of a titanium alloy inductively heated for 900 seconds and then cooled for 60 seconds as a function of distance from the centerline of the heated localized region.

[0031] The reader will appreciate the foregoing details, as well as others, upon considering the following detailed description of certain non-limiting embodiments according to the present disclosure.

DETAILED DESCRIPTION OF CERTAIN NON-LIMITING EMBODIMENTS

[0032] In the present description of non-limiting embodiments, other than in the operating examples or where otherwise indicated, all numbers expressing quantities or characteristics are to be understood as being modified in all instances by the term "about". Accordingly, unless indicated to the contrary, any numerical parameters set forth in the following description are approximations that may vary depending on the desired properties one seeks to obtain by way of the methods according to the present disclosure. At the very least, and not as an attempt to limit the application of the doctrine of equivalents to the scope of the claims, each numerical parameter should at least be construed in light of the number of reported significant digits and by applying ordinary rounding techniques. Also, all ranges provided herein are inclusive of the indicated boundaries or limits. For example, a temperature range of "0.2 to 0.5" of a particular temperature is inclusive of the indicated boundaries of 0.2 and 0.5 of the particular temperature.

[0033] Any patent, publication, or other disclosure material, in whole or in part, that is said to be incorporated by reference herein is incorporated herein only to the extent that the incorporated material does not conflict with existing definitions, statements, or other disclosure material set forth in this disclosure. As such, and to the extent necessary, the disclosure as set forth herein supersedes any conflicting material incorporated herein by reference. Any material, or portion thereof, that is said to be incorporated by reference herein, but which conflicts with existing definitions, statements, or other disclosure material set forth herein is only incorporated to the extent that no conflict arises between that incorporated material and the existing disclosure material.

[0034] There is a need for improved methods to bend and otherwise form hard-to-form metallic materials. For example, the present inventors concluded that it would be advantageous to provide a method of forming hard-to-form metallic materials that does not require the use of open torches, large furnaces and associated logistics, or heating of materials to superplastic temperatures. The present inventors believe that such a method may lower the costs of formed components, increase productivity, and/or reduce the thermomechanical processing equipment infrastructure currently required to form many hard-to-form metallic materials. The present inventors also believe that such a method will enable new part design basis, i.e., the production of parts from alloys not previously used for such parts due to limitations of conventional production techniques.

[0035] FIG. **1** is a flow diagram schematically presenting a non-limiting embodiment according to the present disclosure of a method for elevated temperature forming of a metallic article comprising a hard-to-form metallic material. As used herein, the term "hard-to-form metallic material" refers to metals and metal alloys having high strength and low ductility at a forming temperature, and to metals and metal alloys that flow soften upon deformation. In a non-limiting embodiment, a hard-to-form metallic material has less than a 10% difference in tensile strength and yield strength at a forming temperature. In another non-limiting embodiment, a hard-to-form metallic material is a metal or metal alloy that exhibits a high spring back, such as is the case with titanium alloys, for example. As used herein, hard-to-form metallic materials include, for example, titanium alloys, nickel-base alloys, and specialty steels (e.g., stainless steel, high-strength low-alloy steel (HSLA), and armor steel alloys). Also, as used herein, "metallic" refers to a material or article comprising a metal and/or metal alloy.

[0036] While the embodiment disclosed in FIG. **1** refers to specific hard-to-form metallic materials, the embodiments described herein also may be used in forming high purity metals, commercially pure metals, and other metal alloys that either are or are not considered hard-to-form metallic materials. (Also, in order to reduce repetition in the present discussion, any reference to a "metal alloy" in the succeeding discussion of embodiments according to the present disclosure is inclusive of the unalloyed base metal.) One non-limiting example of a hard-to-form high purity metal that may be processed according to embodiments disclosed herein is high purity zirconium.

[0037] With reference to FIG. **1**, a non-limiting method **10** according to the present disclosure for forming a metallic article, i.e., an article including a hard-to-form metal or metal alloy article, comprises inductively heating **12** a localized region of the metallic article to a forming temperature in a forming temperature range. When the localized region is at the desired forming temperature, the article is bent or otherwise formed **14** in the localized region that has been inductively heated.

[0038] In a non-limiting embodiment, the forming temperature is in a forming temperature range of 0.2 to 0.5 of the melting temperature (T_m) of the metal or metal alloy comprising the metallic article. In another non-limiting embodiment, the forming temperature is in a forming temperature range of 0.24 to 0.3 of a melting temperature of the metal or metal alloy comprising the metallic article. In another non-limiting embodiment, the forming temperature range is about 0.2 of the melting temperature to a temperature less than the recrystallization temperature of the metal or metal alloy comprising the metallic article. As used herein, the "melting temperature" is defined as being the lowest temperature at which incipient melting of the metal or metal alloy occurs. As used herein, the "recrystallization temperature" is defined as the lowest temperature at which the distorted grain structure of a cold-worked metal or metal alloy is replaced by a new, strain-free grain structure during prolonged heating.

[0039] As used herein, a "titanium alloy" is a metallic alloy including titanium as the predominant element. As used herein, a "nickel base alloy" is a metallic alloy including nickel as the predominant element. As used herein, a "specialty steel" is selected from categories of steel including, but not limited to, electric steels, alloy steels, stainless steels (including, ferritic, martensitic, austenitic, super-austenitic, duplex, and precipitation hardening stainless steels), tool steels, maraging steels, armor steel alloys, high strength low alloy steels, and wear steels.

[0040] Again referring to FIG. **1**, forming **14** the metallic article may comprise, but is not limited to, techniques selected from bending, drawing, punching, stamping, and roll forming. In another non-limiting embodiment, the metallic article comprises a mill product. As used herein, a "mill product" is any metallic (i.e., metal or metal alloy) article that is used as-fabricated or is further fabricated into a finished product. In a non-limiting embodiment according to the present disclosure, the mill product is selected from an ingot, a billet, a bloom, a round bar, a square bar, an extrusion, a tube, a pipe, a slab, a sheet, and a plate. In yet another non-limiting embodiment according to the present disclosure, the metallic article comprises a metallic plate, the localized region of the metallic plate that is inductively heated comprises a lineal region, and forming **14** the metallic plate comprises bending the metallic plate in the lineal region of the metallic plate.

[0041] As used herein, a "localized region" is an area of a metallic article that will be plastically deformed during a forming step. A "localized region" also may include one or more areas immediately adjacent to the area of the metallic article that will be plastically deformed. For example, in certain non-limiting embodiments according to the present disclosure, the localized region may extend up to about 0.5 inch (1.27 cm), up to about 1 inch (2.54 cm), up to about 2 inches (5.04 cm), up to about 3 inches (7.62 cm), up to about 4 inches (10.16 cm), or a greater distance from the area of the metallic article that will be plastically deformed. For example, it is envisioned that in addition to inductively heating the area that will be plastically deformed, it may be desirable to inductively heat one or more areas immediately adjacent to the area that will be plastically deformed when the method is conducted on thicker metallic articles and/or to better ensure that the area of the metallic article that is plastically deformed is at the forming temperature during the forming step.

[0042] In a non-limiting embodiment of a method according to the present disclosure, a localized region that is inductively heated is a lineal region. As used herein, a "lineal region" is an elongated region that includes the intended bend line (i.e., the centerline of the bend) of a metallic plate or other article. The lineal region also may extend a distance from the intended bend line. For example, the lineal region may extend up to about 0.5 inch (1.27 cm), up to about 1 inch (2.54 cm), up to about 2 inches (5.04 cm), up to about 3 inches (7.62 cm), up to about 4 inches (10.16 cm), or a greater distance from the intended bend line along all or a region of the length of the intended bend line. In certain embodiments, the distance from the intended bend line defining a boundary of the lineal region increases with increasing thickness of the plate or other article to be bent or otherwise formed using the methods herein.

[0043] In non-limiting embodiments according to the present disclosure, inductively heating a lineal region or other localized region involves utilizing one or more induction heating coils positioned adjacent to the localized region of the plate or other article. FIG. **2** is a schematic representation of a non-limiting embodiment according to the present disclosure of a method of inductively heating **20** a lineal region **22** of a plate **24** of a hard-to-form metal or metal alloy. Lineal region **22** is bounded by lines **22***a* in FIG. **2**. In the non-limiting embodiment represented by FIG. **2**, the lineal region **22** is inductively heated by two induction coils **26** positioned adjacent to opposite surfaces **28**,**29** of the lineal region **22** of the plate **24**. While FIG. **2** depicts two induction coils **26** being utilized to heat the lineal region **22** of the plate **24**, it is understood that one induction coil **26** or more than two induction coils **26** could be utilized to heat the lineal region **22** of the plate **24**. Accordingly, for example, it is within the scope of this disclosure to position one or more induction coils adjacent to one or both opposite surfaces of a lineal region or other localized region of a metallic plate or other article to heat the localized region of the article to a forming temperature. It will be understood that the foregoing discussion concerning the number and positioning of induction coils relative to a localized region of a metallic article applies to any geometry of localized region that may be used in the methods according to the present disclosure.

[0044] For purposes herein, induction heating using an arrangement of induction coils such as, for example, induction coils **26** positioned directly adjacent to a metal or metal alloy article such as, for example, plate **24** is referred to herein as "direct" induction heating. In direct induction heating, one or more induction coils or other induction heating devices induce a current in a localized region of a metallic article and thereby cause the temperature of the localized region to increase. Direct induction heating may be contrasted with "indirect" induction heating, wherein a current is induced in and thereby heats a region of a metallic object, and the metallic object heats a localized region of a metallic article through conduction of heat from the inductively heated metallic object to the metallic article. Thus, in direct induction heating, the induction heating device inductively heats the metal or metal alloy article to be bent or otherwise formed without reliance on inductively heating an interposing metal or metal alloy object.

[0045] Induction heating is a technique used to heat an electrically conductive object, such as a metal or metal alloy object, by electromagnetic induction, wherein a high frequency alternating current is passed through an electromagnet and induction coil. The induction coil is positioned adjacent to the metallic object, and the current within the coil generates eddy currents within the object. Electrical resistance within the metallic object results in Joule heating of the object. The frequency of alternating current that must be used to inductively heat a particular metal or metal alloy object depends on the object size, the composition of the metal or metal alloy, the particular coupling between the induction coil and the object to be heated, and the depth of penetration of the induced eddy currents. In non-limiting embodiments according to the present disclosure, the induction heating device used to heat the lineal region or other localized region of an article comprising a hard-to-form metallic material employs an alternating current frequency specifically tuned to efficiently and adequately heat the metallic article. Induction heating is known to those having ordinary skill in the art, and further elaboration of the principles of and manner for carrying out the technique is believed to be unnecessary in the present disclosure.

[0046] In certain non-limiting embodiments according to the present disclosure, the forming or bending temperature is within a range of about 0.2 times the melting temperature (0.2 T_m) of the hard-to-form metal or metal alloy, up to about 0.5 times the melting temperature (0.5 T_m) of the hard-to-form metal or metal alloy. Therefore, given the relatively low temperatures utilized, an aspect of non-limiting embodiments according to the present disclosure is that the embodiments may be considered to be "warm forming" methods. It was unexpected and surprising to the present inventors that hard-to-form metallic materials, such as, but not limited to, titanium alloys, nickel-base alloys, and specialty steels, can be bent or otherwise formed at temperatures substantially lower than the materials' melting temperatures without fracturing the material during forming and wherein after forming, the plastically deformed region is completely or substantially free of surface defects such as, for example, linear indications in the form of macro-surface and micro-surface cracking, resulting from the bending or other forming step.

[0047] In a non-limiting embodiment according to the present disclosure wherein the method is performed on a titanium alloy article, the forming or bending temperature range may be in a forming or bending temperature range of 750° F. (398.9° C.) to 850° F. (454.4° C.), or in a forming or bending temperature range of 800° F. (426.7° C.) to 850° F. (454.4° C.). According to one non-limiting embodiment, the forming or bending temperature for a titanium alloy article is about 800° F. (426.7° C.), while in another non-limiting embodiment the forming or bending temperature for a titanium alloy article is about 850° F. (454.4° C.). According to certain non-limiting embodiments, when the metallic article that is being bent or otherwise plastically deformed consists of or comprises Ti-4Al-2.5V-1.5Fe-0.25O_2 alloy (UNS R54250), the forming or bending temperature range may be from 728° F. to 874° F. (387° C. to 468° C.). In other non-limiting embodiments according to the present disclosure wherein the metallic article consists of or comprises a titanium alloy, the forming or bending temperature range may be from about 1000° F. (555.6° C.) below the beta transus temperature (T_β) of the titanium alloy up to about 700° F. (388.9° C.) below the beta transus temperature of the titanium alloy, i.e., in a temperature range of T_β−1000° F. to T_β−700° F. (T_β−555.6° C. to T_β−388.9° C.).

[0048] Most conventional processes for forming titanium alloys use temperatures greater than 1000° F. (537.8° C.). At these "hot forming" temperatures, surfaces of the titanium alloys may oxidize, forming an alpha-case. Alpha-case is an oxygen-enriched phase resulting when titanium and its alloys are exposed to heated air or oxygen. Because alpha-case is brittle and tends to cause fatigue cracks in the alloy, it typically is removed in subsequent processing steps. Little or no alpha-case forms at the forming temperatures used in various non-limiting embodiments of the forming methods disclosed herein.

[0049] In addition, above about 1000° F. (537.8° C.) the mechanical properties of titanium alloys may change. For example, ballistic properties required of titanium alloys for armor applications such as, for example, high toughness, may be lost on thermo-mechanical processing a titanium alloy at hot forming temperatures. In such case, heat treatments subsequent to hot forming may be required to restore desired mechanical properties in the alloys. For some hard-to-form metallic materials, it may not be possible to restore the desired mechanical properties using post-forming heat treatments. The present inventors observed that subjecting titanium alloys and other metal alloys to the relatively low forming temperatures used in non-limiting embodiments disclosed herein does not significantly affect important mechanical properties of the alloys. As suggested, particularly important mechanical properties may be those required for ballistic armor and/or other applications.

[0050] In certain non-limiting embodiments of the methods according to the present disclosure in which titanium alloys are bent or otherwise formed, as the bending or forming temperature is lowered, both the ability to form or bend to tighter radii and the reproducibility of the method decreases. For example, as the bending or forming temperature is lowered, a higher incidence of "spring back" of the bent or otherwise formed plate or other article occurs. As is known in the art, spring back occurs when, for example, after a plate is bent, the bent plate reverts to a larger bend radius than to which it was bent. Further, as the bending temperature used is lowered, the risk that micro-cracking will occur in the bend line increases. Therefore, in a non-limiting embodiment according to the present disclosure of a method for bending or other forming of titanium alloy articles, a lower limit for the bending or other forming temperature is about 750° F. (398.9° C.). In another non-limiting embodiment according to the present disclosure of a method for bending or other forming of titanium alloy articles, a lower limit for the bending or other forming temperature is about 700° F. (371.1° C.). In yet another non-limiting embodiment according to the present disclosure of a method for bending or other forming of titanium alloy articles, a lower limit for the bending or other forming temperature is in a forming temperature range of about 700° F. (371.1° C.) to about 900° F. (482.2° C.). In general, in various non-limiting embodiments according to the present disclosure of methods for bending and other forming of metals and metal alloys, including hard-to-form metallic materials such as, but not limited to, titanium alloys, nickel-base alloys, and specialty steels (e.g., stainless steel, high-strength low-alloy steel (HSLA), armor steel alloys, and the like), a lower limit of the forming temperature range is about 0.2 T_m. Also, in general, in various non-limiting embodiments according to the present disclosure of methods for bending and other forming of metals and metal alloys, including hard-to-form metallic materials such as, but not limited to, titanium alloys, nickel-base alloys, and specialty steels (e.g., stainless steel, high-strength low-alloy steel (HSLA), armor steel alloys, and the like), a forming temperature range is about 0.2 T_m to about 0.5 T_m.

[0051] During development of a "warm forming" method for forming or bending hard-to-form metallic materials, the present inventors observed that an entire plate could be heated in a furnace to a bending temperature as disclosed herein and successfully bent when the plate is transferred from the furnace to a press break before the plate cools outside of the bending temperature range. However, a furnace capable of heating an entire plate must be relatively large, and heating the entire plate to a uniform temperature can take significant time, reducing yield and complicating the handling from the furnace to the forming equipment.

[0052] In embodiments according to the present disclosure, localized induction heating of a lineal or other localized region of a metallic article may be accomplished relatively quickly. In certain non-limiting embodiments, inductively heating a lineal or other localized region may be accomplished in, for example, 5 to 10 seconds, no more than 1 minute, no more than 2 minutes, no more than 20 minutes, no more than 30 minutes, or no more than 60 minutes. Other induction heating times possible in certain non-limiting embodiments may be from about 3 minutes to about 20 minutes. Heating times may be extended to better ensure that "cold spots" are not present in the lineal region or other localized region that is heated. As used herein, a "cold spot" is an area within a lineal or other localized region that is cooler than the desired bending or other forming temperature and is outside of the bending or other forming temperature range. Thicker metallic plate and other thicker metallic articles may require longer heating times to reach the desired forming temperature. However, in certain non-limiting embodiments according to the present disclosure, if the one or more induction coils are properly tuned to couple with and heat the metal or metal alloy article that is to be plastically deformed, and the induction coils are positioned properly with respect to the lineal or other localized region of the plate or other article, the localized region can be heated to the desired forming temperature without cold spots in 30 seconds or less. In a non-limiting embodiment, a lineal region of a 1 inch-thick 18 inch×120 inch titanium alloy plate can be directly inductively heated to a uniform bending temperature of about 850° F. (454.4° C.) within 10 minutes, without cold spots.

[0053] Referring again to FIG. **1**, after inductively heating the hard-to-form metallic plate or other article, the article is transferred to a forming apparatus. In the non-limiting embodiment depicted in FIG. **2**, for example, the lineal region **22** of the plate **24** is rapidly inductively heated by induction coils **26** to a bending temperature within a bending temperature range, and the plate **24** is then bent to a desired bend radius on a forming apparatus (not shown). In a non-limiting embodiment according to the present disclosure, bending or forming is accomplished on a press brake or other forming apparatus. The forming apparatus may be located close to the induction heating device to better ensure that the inductively heated lineal or other localized region of the metallic plate or other article can be bent or otherwise formed before the temperature of the localized region cools to a temperature below the forming temperature range.

[0054] While the non-limiting embodiment schematically illustrated in FIG. **2** involves bending of plate **24** after it is heated to a bending temperature, it will be recognized that other forming processes for plastically deforming the heated article are within the scope of embodiments disclosed herein. For example, such other forming processes include, but are not limited to, drawing, punching, stamping, roll forming, and like forming processes. Also, while certain embodiments discussed herein involve inductively heating a lineal or other localized region and bending the heated article, it will be understood that the present invention is not limited to such arrangements. For example, non-limiting embodiments according to the present disclosure directed to a stamping or coining process may involve directly and/or indirectly inductively heating a localized region of a metallic article that will be plastically deformed in a stamping or coining operation. Other configurations of induction heating of a localized region of a metallic article that are encompassed within the present disclosure may be specific to other forming processes, and one having ordinary skill considering the present disclosure may adapt the methods herein for such applications without undue experimentation.

[0055] Titanium alloys that may be formed using certain non-limiting embodiments of warm forming according to the present disclosure include, but are not limited to, near-alpha titanium alloys, alpha+beta titanium alloys, and beta titanium alloys, including, for example, near-beta and metastable beta titanium alloys. In certain non limiting embodiments, titanium alloys that can be bent or otherwise formed using warm forming methods according to the present disclosure include, but are not limited to ASTM Grades 5, 6, 12, 19, 20, 21, 23, 24, 25, 29, 32, 35, 36, and 38 titanium alloys. In certain non-limiting embodiments, a localized region of an article of Grade 38 titanium alloy (UNS R54250) is inductively heated and bent or otherwise formed according to embodiments of the warm forming methods herein. In still another non-limiting embodiment, a localized region of an article of Grade 5 titanium alloy (UNS R56400), which also is referred to as Ti-6-4 alloy and Ti-6Al-4V alloy, is inductively heated and warm bent or otherwise warm formed according to embodiments disclosed herein. In yet another non-limiting embodiment, a localized region of Grade 35 titanium alloy (UNS R56340), which nominally includes, in weight percentages based on total alloy weight, 4.5% aluminum, 2% molybdenum, 1.6% vanadium, 0.5% iron, 0.3% silicon, and balance titanium and incidental impurities, is inductively heated and warm bent or otherwise warm formed according to embodiments disclosed herein.

[0056] According to a non-limiting aspect of the present disclosure, a warm forming method according to the disclosure includes inductively heating a lineal region or other localized region of a metallic article consisting of a high hard specialty steel to a forming temperature, and bending or otherwise forming the high hard specialty steel article by plastically deforming the lineal or other localized region. According to a non-limiting embodiment of this disclosure, a high hard specialty steel that is a high hard specialty steel armor is processed according to methods herein. According to certain non-limiting embodiments, a high hard specialty steel processed by methods herein is selected from the group consisting of a 400 BHN steel armor, a 500 BHN steel armor alloy, a 600 BHN steel armor alloy, a 700 BHN steel armor, and a high strength low alloy steel.

[0057] The armor steel alloys can be generally classified or identified according to their hardness as follows: Rolled Homogeneous Armor ("RHA") alloys with hardness range of 212-388 BHN (Brinell hardness number) under MIL-A-12560H; High Hard Armor ("HHA") alloys with hardness range of 477-535 BHN under MIL-DTL-46100E, and Ultra High Hard Armor ("UHH") alloys with minimum hardness of 570 BHN under MIL-DTL-32332. According to certain non-limiting embodiments, armor steel alloys processed by methods herein include, but are not limited to RHA, HHA, and UHH alloys.

[0058] In a non-limiting embodiment, a localized region of a plate or other article of an armor steel alloy comprising one of an RHA alloy, an HHA alloy, and a UHH alloy is inductively heated and warm bent or otherwise formed according to embodiments disclosed herein. In another non-limiting embodiment, a localized region of a plat or other article of a 500 BHN steel armor alloy is inductively heated and warm bent or otherwise formed according to embodiments disclosed herein. One non-limiting example of a 500 BHN steel armor alloy that may be processed according to the present disclosure is ATI 500-MIL® high hard specialty steel armor alloy, available from ATI Defense, Washington, Pa., an Allegheny Technologies Incorporated market sector team. In still another non-limiting embodiment, a localized region of a plate or other article of a 600 BHN steel armor alloy is inductively heated and warm bent or otherwise formed according to embodiments disclosed herein. A non-limiting example of a 600 BHN steel armor alloy that may be processed according to the present disclosure is ATI 600-MIL® high hard specialty steel armor available from ATI Defense.

[0059] It is recognized that the bending or other forming of metal and metal alloy articles becomes increasingly difficult as the thickness of the articles increase. As discussed above, the present inventors surprisingly discovered that plates of hard-to form metallic materials can be inductively heated in a localized region to a relatively low forming temperature and bent or otherwise formed without resulting in formation of bending surface defects such as micro-cracking. In a non-limiting embodiment, the metal or metal alloy plate or other article processed by methods herein is at least 0.125 inch (3.175 mm) thick. In another non-limiting embodiment, the metal or metal alloy plate or other article processed using the methods herein is at least 0.1875 inches (4.763 mm) thick. The thickness of plates or other articles capable of being bent or otherwise formed according to non-limiting embodiments disclosed herein is up to about 2 inches (5.08 cm) or, in some cases, up to about 1 inch (2.54 cm), wherein the thickness is in the region that is to be plastically deformed in the method. According to a non-limiting embodiment of a method according to the present disclosure for bending or otherwise forming titanium alloy plate, a brake press or other forming equipment having a capacity of 1000 tons to 1500 tons (8.896 MN to 13.34 MN) is sufficient to bend a 1.5 inch (3.81 cm) thick plate. It is believed that the thickness of plate that can be bent or otherwise formed according to embodiments of warm forming methods herein is limited only by the capacity of the brake press or other forming equipment used. It is recognized that the bending or other forming of metal and metal alloy sheet, i.e., product having a thickness less than 0.1875 inches (4.763 mm), is also within the scope of embodiments disclosed herein.

[0060] Because forming temperatures employed in the methods herein, e.g., forming temperatures in a temperature range of 0.2 T_m to 0.5 T_m, are relatively low, certain mechanical properties of the lineal or other localized region of the metal or metal alloy article that is inductively heated are not substantially changed after the bending or other forming step. As used herein, a mechanical property does not "substantially change" if the property does not change or changes no greater than 10%, or in some cases no greater than 5%, from the original value.

[0061] It was particularly surprising to the present inventors that hard-to-form metallic materials such as, but not limited to, titanium alloys, nickel-base alloys, and specialty steels (e.g., stainless steel, high-strength low-alloy steel (HSLA), armor steel alloys, and the like) could be locally inductively heated to relatively low temperatures and bent to tight radii according to certain non-limiting embodiments of the present disclosure. For example, according to a non-limiting embodiment herein including inductively heating a lineal region of and bending a metallic article selected from a titanium alloy plate, a nickel-base alloy plate, and a specialty steel plate, the form is bent to a bend radius of at least 6 t. As used herein, a "bend radius" is the radius, measured to the inside curvature, to which a plate or other metallic article can be bent without fracturing, forming surface cracks, or significantly degrading the mechanical properties of the metallic article in the bend region. The value of the bend radius is given with respect to the thickness, "t", of the plate or other article. A plate bent to a radius of 1 t, for example, includes a bend having a radius, measured on the inside of the bend curvature, that is equal to the thickness of the plate. In other non-limiting embodiments including inductively heating a lineal region of and bending a metallic article selected from a titanium alloy plate, a nickel-base alloy plate, and a specialty steel plate, the article is bent to a radius of at least 4 t, or at least 2 t. In still another non-limiting embodiment including inductively heating a lineal region of and bending a metallic article selected from a titanium alloy plate, a nickel-base alloy plate, and a specialty steel plate, the article is bent to a radius of at least 1 t.

[0062] A non-limiting aspect of this disclosure employs indirect induction heating to heat a lineal or other localized region of a metallic plate or other article, and a forming step in order to warm form the metallic article. FIG. **3** is a flow diagram of a non-limiting embodiment according to the present disclosure of a method **30** for bending or otherwise forming a plate or other article of, for example, a hard-to-form metallic material such as a titanium alloy, a nickel-base alloy, or a specialty steel (e.g., stainless steel, high-strength low-alloy steel (HSLA), armor steel, and the like). FIG. **4** is a schematic depiction of an arrangement **40** of materials and equipment used in a non-limiting embodiment according to the present disclosure, wherein indirect induction heating is used to indirectly heat a lineal or other localized region of a metallic plate or other article in order to warm form the metallic article.

[0063] Referring to method **30** and arrangement **40** of FIGS. **3** and **4**, respectively, a non-limiting embodiment of indirect induction heating for warm forming a metallic article includes placing **32** a metallic article **42** on a ferrous alloy surface **44**. In a non-limiting embodiment, the metallic article **42** comprises a hard-to-form metallic material. After placing the metallic article **42** on the ferrous alloy surface **44**, a localized region **46** of the ferrous alloy surface **44** that is in contact with a localized region **48** (schematically bounded by lines **48***a*) of the metallic article **42** is inductively heated **34** to a predetermined temperature. Inductively heating the ferrous alloy surface **44** conductively heats the localized region **48** of the metallic article **42** to a forming temperature within a forming temperature range.

[0064] In a non-limiting embodiment, the predetermined temperature to which the localized region **46** of the ferrous alloy surface **44** is heated is the forming temperature of the metallic article **42**. In another non-limiting embodiment, the predetermined temperature to which the localized region **46** of the ferrous alloy surface **44** is heated is a forming temperature in a forming temperature range of the metallic article **42**. In yet another non-limiting embodiment, the predetermined temperature to which the localized region **46** of the ferrous alloy surface **44** is heated is higher than the forming temperature of the metallic article **42**. Preferably, however, the temperature to which the localized region **48** of the metallic article **42** is conductively heated does not exceed the upper limit of the forming temperature range of the metallic article **42**.

[0065] As further illustrated in FIG. **4**, in arrangement **40**, inductively heating a localized region **46** of the ferrous alloy surface **44** may utilize one or more induction coils **50** positioned on an opposite side **52** of the localized region **46** of the ferrous alloy surface **44** that is to be inductively heated. While FIG. **4** depicts an arrangement in which one induction coil **50** heats the localized region **46** of the ferrous alloy surface **44**, it will be understood that more than one induction coil could be utilized to heat the localized region **46** of the ferrous alloy surface **44**. It also will be understood that the above discussion concerning the possible number of induction coils and their positions to heat a localized region as depicted in the non-limiting embodiment of FIG. **4**, applies equally for other localized region geometries that may be used in the various types of warm forming operations within the scope of this disclosure.

[0066] In a non-limiting embodiment according to the present disclosure utilizing indirect induction heating, when the localized region **48** of the metallic article **42** is conductively heated by the localized region **46** of the ferrous alloy surface **44** to a forming temperature in a forming temperature range, the metallic article **42** is then bent or otherwise formed **14** by plastically deforming the metallic article **42** in the localized region **48** of the metallic article **42**.

[0067] In a non-limiting embodiment according to the present disclosure, the indirect induction heating method disclosed herein may be used to bend and otherwise form metallic articles comprising hard-to-form metallic materials, such as, but not limited to, titanium alloys, nickel-base alloys, and specialty steels (e.g., stainless steel, high-strength low-alloy steel (HSLA), armor steels, and the like). Also, in a non-limiting embodiment according to the present disclosure, the indirect induction heating method disclosed herein heats the localized region of the metallic article to a forming temperature in a forming temperature range of 0.2 to 0.5 of a melting temperature of the metal or metal alloy comprising the metallic article. In another non-limiting embodiment according to the present disclosure, the indirect induction heating method disclosed herein heats the localized region of the metallic article to a forming temperature in a forming temperature range of 0.24 to 0.30 of a melting temperature of the metal or metal alloy comprising the metallic article.

[0068] In certain non-limiting embodiments of the methods disclosed herein, and with particular reference to FIGS. **3** and **4**, forming **36** comprises processes such as, but not limited to bending, drawing, punching, stamping, and roll forming. In another non-limiting embodiment, the metallic article **42** consists of or comprises a mill product such as, for example, an ingot, a billet, a bloom, a round bar, a square bar, an extrusion, a tube, a pipe, a slab, a sheet, and a plate. In yet another non-limiting embodiment, the metallic article **42** is a metal alloy plate, the localized region of the metal alloy plate is a lineal region, and forming **36** comprises bending the metal alloy plate in the lineal region of the metal alloy plate.

[0069] Again referring to FIG. **4**, in a non-limiting embodiment, the localized region **48** of the metallic article **42** includes a region of metallic material immediately adjacent to the metallic material that will be plastically deformed during the forming step **36**. In non-limiting embodiments, the localized region **48** includes a region of metallic material that extends up to about 0.5 inch (1.27 cm), up to about 1 inch (2.54 cm), up to about 2 inches (5.04 cm), up to about 3 inches (7.62 cm), up to about 4 inches (10.16 cm), or a greater distance away from the metallic material of the article **42** that will be plastically deformed during the forming step **36**. It is envisioned that in order to form thicker product forms, the area of the localized region may be increased to ensure that the region of the metallic material that undergoes plastic deformation during forming is at the desired bending temperature or other forming temperature.

[0070] In a non-limiting embodiment according to the present disclosure involving indirect induction heating, a localized region **48** of the metallic article **42** is a lineal region. In certain non-limiting embodiments utilizing indirect induction heating, the lineal region is a region including and surrounding the bend line of a plate or other metallic article that is to be bent, and the lineal region may extend up to about 0.5 inch (1.27 cm), up to about 1 inch (2.54 cm), up to about 2 inches (5.04 cm), up to about 3 inches (7.62 cm), up to about 4 inches (10.16 cm), or a greater distance on one or both sides of the bend line, along all or a portion of the bend line. It is envisioned that in order to bend thicker plate, the area of the lineal region may also be increased.

[0071] In a non-limiting embodiment utilizing indirect induction heating for warm forming a metallic article **42**, the metallic article **42** comprises a titanium alloy. In certain non-limiting embodiments, the titanium alloy is selected from ASTM Grades 5, 6, 12, 19, 20, 21, 23, 24, 25, 29, 32, 35, 36, and 38 titanium alloys.

[0072] In another non-limiting embodiment utilizing indirect induction heating for warm forming a metallic article **42**, the metallic article comprises a high hard specialty steel. In a non-limiting embodiment, the metallic article **42** comprises a material selected from a 400 BHN steel armor alloy, a 500 BHN steel armor alloy, a 600 BHN steel armor alloy, a 700 BHN steel armor alloy, a high strength low alloy steel, an RHA alloy, an HHA alloy, and a UHH alloy.

[0073] With particular reference to FIG. **4**, a non-limiting aspect according to the present disclosure includes using indirect induction heating to bend a metallic article that is in the configuration of a plate **42**. In a non-limiting embodiment, the localized region **48** of the plate comprises a lineal region, and forming **36** the plate comprises bending the plate in the lineal region.

[0074] In non-limiting embodiments, the metallic article **42** has a thickness of at least 0.125 inch (3.175 mm). In other non-limiting embodiments, the metallic article **42** has a thickness of at least 0.1875 inches (4.763 mm).

[0075] When the metallic material from which the plate **42** is comprised is Ti-4Al-2.5V-1.5Fe-0.25O_2 titanium alloy (UNS 54250), in a non-limiting embodiment the forming temperature range is 728° F. to 874° F. (387° C. to 468° C.). In another non-limiting embodiment, when the metallic material is a titanium alloy, the forming temperature range is 700° F. to 900° F.

[0076] In non-limiting embodiments, localized region **48** of the metallic article **42** may have a bend radius of at least 1 t after forming **36**. In other non-limiting embodiments, localized region **48** of the metallic article **42** may have a bend radius of at least 6 t, at least 4 t, or at least 2 t after forming **36**.

[0077] In certain non-limiting embodiments, the metallic article is a mill product. In another non-limiting embodiment, the metallic article **42** is one of an ingot, a billet, a bloom, a round bar, a square bar, an extrusion, a tube, a pipe, a slab, a sheet, and a plate.

[0078] A non-limiting aspect of this disclosure is directed to a method for bending a metallic plate using localized indirect induction heating. Because a metallic plate is an embodiment of metallic article, reference is again made to FIGS. **3** and **4**. A method **30** and arrangement **40** for bending a metallic plate **42** comprises: placing **32** a metallic plate **42** including a material selected from a metal and a metal alloy on a ferrous alloy surface **44**; inductively heating **34** a lineal surface region **46** of the ferrous alloy surface **44** in contact with a lineal region **48** of the metallic plate **42** to a predetermined temperature and thereby conductively heating the lineal region **48** of the plate **42** to a bending temperature within a bending temperature range; and bending **36** the plate **42** in the lineal region **48**.

[0079] Bending is one embodiment of forming. Accordingly, it will be understood that all of the conditions described herein that are useful for localized indirect induction heating for warm forming metallic articles equally apply to non-limiting embodiments of localized indirect induction heating for warm bending metallic plates. In addition, metallic plates may include any of the metallic materials specifically disclosed herein in various non-limiting embodiments and otherwise, and the plates may be processed by the various non-limiting embodiments of localized indirect induction heating discussed herein.

[0080] In a non-limiting embodiment, the metallic plate **42** has a thickness of at least 0.125 inch (3.175 mm). In another non-limiting embodiment, the metallic plate has a thickness of at least 0.1875 inches (4.763 mm).

[0081] One non-limiting aspect of this disclosure is directed to a device for indirect localized induction heating of articles comprising a metallic material selected from a metal and a metal alloy. Referring now to FIG. **5**, in a non-limiting embodiment, a device **60** comprises a support **62** including a ferrous alloy surface **64**, and at least one induction heating device **66**. The at least one induction heating device **66** is positioned and adapted to inductively heat a localized region **67** (bounded by lines **67***a*) of the ferrous alloy surface. While FIG. **5** depicts one induction heating device **66** utilized to heat a localized region **67** of the ferrous alloy surface **64**, it will be understood that more than one induction heating device **66** could be utilized to heat a localized region **67** of the ferrous alloy surface **64**. Also, while FIG. **5** depicts a device for inductively heating a localized region **67** having a generally lineal configuration, it will be understood that the scope of this disclosure also includes varying the number, shapes, and/or positions of induction coils to inductively heat localized regions having other geometric shapes and/or orientations and which may be useful for various types of forming operations. In a non-limiting embodiment, the inductively heated localized region of the ferrous alloy surface is adapted to conductively heat a localized region of a metallic article including a material selected from a metal and a metal alloy that is positioned on the ferrous alloy surface to a predetermined temperature.

[0082] In a forming operation, such as in bending a metallic plate or other metallic article, for example, the at least one induction heating device **66** is energized to inductively heat the localized region **67** of the ferrous alloy surface **64** to a predetermined temperature. In a non-limiting embodiment, the predetermined temperature is a bending temperature of a metal or metal alloy plate or other article that is to be bent. The metal or metal alloy article to be bent (not shown) is placed in contact with the ferrous alloy surface **64**. A localized region of the metal or metal alloy plate in contact with the inductively heated localized region **67** of the ferrous alloy plate is conductively heated to the predetermined temperature, which, in a non-limiting embodiment, is the temperature at which the metal or metal alloy plate is to be when it is bent.

[0083] In a non-limiting embodiment, the ferrous alloy surface **64** and the support **62** comprise the same ferrous alloy. In another non-limiting embodiment, the ferrous alloy surface **64** and the support **62** are one-piece, and the ferrous alloy surface **62** is a surface of the support **62**. In one non-limiting embodiment, the support **62** comprises at least one of a ferrous alloy sheet and a ferrous alloy plate. In certain non-limiting embodiments, the ferrous alloy surface comprises a material selected from carbon steel, a steel alloy, and a stainless steel. In other non-limiting embodiments, the ferrous alloy surface **64** is a surface of the support **62**, and the surface **64** and support **62** are composed of at least one of a low carbon steel, a steel alloy, and a ferritic stainless steel alloy.

[0084] In a non-limiting embodiment according to the present disclosure, one or more of the induction heating devices **66** comprises one or more induction coils. In another non-limiting embodiment, the one or more induction heating devices **66** are tuned to a frequency that couples with the specific material of the ferrous alloy surface. For example, the ferrous alloy surface **64** may be composed of a steel alloy and the frequency of the alternating magnetic field of the induction coil is adjusted to optimally heat the steel alloy. The tuning of induction coils to heat specific materials is known to a person skilled in the art and need not be elaborated upon further here. In another non-limiting embodiment, the at least one induction heating device is positioned opposite the ferrous alloy surface **64** and is adapted to inductively heat a lineal region of the ferrous alloy surface **64**.

[0085] In certain non-limiting embodiments, the device **60** may be in the form of an induction heating table comprising legs **68**. In addition, optionally, the device may include insulation **69** in areas away from the localized region **67** to better contain the heat within the localized region **69** and to insulate the water cooled induction coils **66**.

[0086] One non-limiting aspect of this disclosure is directed to a device for direct induction heating of a localized region of a metallic plate or other metallic article. Referring to FIG. **6**, in a non-limiting embodiment, a device **70** comprises a support **71** including a support surface **72**, and at least one induction heating device **73**. The support **71** and support surface **72** are constructed from one or more materials that are not inductively heated by the at least one induction heating device **73**. For example, the support **71** and support surface **72** may be constructed from one or more materials that are not electrically conductive and, therefore, cannot be heated using induction. In a non-limiting embodiment, the support **71** and the support surface **72** comprise a refractory material. As used herein, the term "refractory material" refers to non-metallic materials having chemical and physical properties that allow them to withstand high temperature such as, for example, temperatures greater than 1,000° F. (538° C.). Refractory materials that may be used in fabricating the support **71** and support surface **72** include, but are not limited to, aluminum oxide, silicon oxide, aluminosilicates, magnesium oxide, zirconium oxide, calcium oxide, silicon carbide, fire clay, fire brick, magnesite ore, dolomite ore, chrome ore, and mixtures thereof. In a non-limiting embodiment, the support **71** and support surface **72** comprise the same refractory material. However, it will be understood that the support **71** and support surface **72** may comprise different refractory materials, or other suitable materials

[0087] The at least one induction heating device **73** is positioned and adapted to inductively heat a localized region **74** (bounded by lines **74***a*) of a metallic article **75** that is positioned on the support surface **72** of the support **71**. It is understood that the metallic article **75** is not an element of the device **70**, and is included in FIG. **6** to better illustrate the function of the device **70**. While FIG. **6** depicts one induction heating device **73** to heat a localized region **74** of a metallic article **75** disposed on the support surface **72**, it will be understood that more than one induction heating device **73** could be utilized to heat a localized region **74** of metallic article **75** positioned on the support surface **72**. In addition, while the non-limiting embodiment of FIG. **6** depicts an induction coil **73** positioned under the support **71**, in another non-limiting embodiment at least one induction coil or other induction heating device **73** may be embedded in the support. Also, while FIG. **6** depicts a device for direct inductive heating of a localized region **74** having a generally lineal configuration, it will be understood that the scope of this disclosure also includes varying the number, shapes, and/or positions of induction coils to directly inductively heat localized regions having other geometric shapes and/or orientations and which may be useful in various types of forming operations.

[0088] In a forming operation, such as bending a metallic plate or other metallic article, for example, the at least one induction heating device **73** of device **70** is energized to directly inductively heat the localized region **74** of the metallic article **75** to a predetermined temperature. In a non-limiting embodiment wherein the metallic article **75** is a metallic plate and the forming operation is a bending operation, the predetermined temperature is a bending temperature of the metal plate **75** within a bending temperature range.

[0089] In certain non-limiting embodiments wherein the induction heating device **73** is one or more water-cooled induction coils, the device **70** may be in the form of an induction heating table comprising legs **76**. In addition, optionally, the device may include thermal insulation **77** to better contain the heat within the localized region **74** and to insulate the water cooled induction coils **73**.

[0090] With regard to various non-limiting embodiments of direct and indirect localized induction heating according to the present disclosure, it will be appreciated that the positioning of induction coils with respect to the localized region to be heated affects the temperature distribution in the localized region being heated. FIGS. **7***a* and **7***b* are schematic representations of non-limiting embodiments of a support **62**,**71** for direct induction heating device **70** and an indirect induction heating device **60** for heating a localized region of a metallic article. The support **62**,**71** includes a surface **64**,**72** and an opposing surface **80**. In non-limiting embodiments of a device **60**,**70**, at least one induction coil **66**,**73** may be positioned adjacent to the opposing surface. The non-limiting embodiment of FIGS. **7***a* and **7***b* depict portions of six induction coils **66**, **73**, wherein the ends of each coil **66**,**73** are connected to the electromagnet power supply. However, the depiction of FIGS. **7***a* and **7***b* can also be interpreted to represent a non-limiting embodiment including one induction coil that is positioned adjacent to the opposing surface and has a serpentine shape, and wherein only the outermost sections of the coil **66**,**73** are connected to the electromagnet power supply. The bend sections of the serpentine induction coil connecting the portions of the coils that are shown in FIGS. **7***a* and **7***b* are not shown in those figures.

[0091] In FIGS. **7***a* and **7***b*, a distance of the at least one induction coil **66**,**73** from the opposing surface is represented by arrow A. In a non-limiting embodiment, the distance A is about 0.5 inches (1.27 cm). The distance between the coils or section of the at least one coil **66**,**73** is represented by the arrows B. In a non-limiting embodiment, the distance B is about 3 inches (7.62 cm). The thickness of a support **62**,**71** is represented by arrow C. In a non-limiting embodiment, the distance C is about 1 inch (2.54 cm).

[0092] In a non-limiting embodiment of a device **60**,**70**, the frequency and power of the electromagnet power supply are selected to effectively heat the localized region **67** of the ferrous alloy surface **64** in the indirect induction heating device **60**, or the localized region **74** of the specific metallic article **75** in the direct induction heating device **70**. In a non-limiting embodiment of a direct induction heating device for heating of titanium and titanium alloys, an electromagnet power supply may be operated at 150 KW and 1 KHz at about 6 KA.

[0093] Referring now to FIG. **8**, another non-limiting aspect of this disclosure is directed to a system for bending or otherwise forming a metallic plate or other metallic article including a material selected from a metal and a metal alloy. In a non-limiting embodiment, the system comprises a heating device **60**,**70**, as discussed in, for example, various non-limiting embodiments herein, and a bending apparatus **80** or other forming apparatus positioned proximate or adjacent to the heating device and adapted to bend or otherwise form the metallic article along (i.e., in) a lineal or other localized region before a temperature of the lineal or other localized region cools below a desired temperature range. In non-limiting embodiments, the heating device **60**,**70** heats a lineal or localized region to a bending temperature or other forming temperature in a bending temperature or other forming temperature range. In a non-limiting embodiment the bending or forming apparatus is positioned proximate to the heating device and adapted to bend or otherwise form the metallic article along (i.e., in) a lineal or other localized region before a temperature of the lineal or other localized region cools below the bending or other forming temperature range.

[0094] Referring to FIG. **9**, still another aspect of the present disclosure is directed to a formed ballistic armor plate **90**. In a non-limiting embodiment, a formed ballistic armor plate **90** according to this disclosure has a thickness of "t" designated by arrows **92***a* and **92***b*, and includes at least one bend region **94** having a bend radius of about 2 t, as depicted by arrow **96**. In non-limiting embodiments according to this disclosure, the ballistic armor plate **90** has a thickness "t" of at least 0.125 inches (3.175 mm), or at least 0.1875 inches (4.763 mm). While FIG. **9** depicts a formed ballistic armor plate **90** having two bend regions **94** with a bend radius **96** of about 2 t, other non-limiting embodiments of a formed ballistic armor plate **90** according to this disclosure have at least one bend region **94** with a bend radius **96** of at least 1 t, at least 2 t, at least 4 t, or at least 6 t. In another embodiment, the formed ballistic armor plate comprises one of a titanium alloy, a nickel-base alloy, and a specialty steel (e.g., a stainless steel, a high-strength low-alloy steel (HSLA), an armor steel, and the like). In another non-limiting embodiment according to this disclosure, the bend region **94** of a ballistic armor plate **90** is free of surface defects, linear indications, and cracks.

[0095] Another aspect of this disclosure is directed to an article of manufacture that comprises an embodiment of the formed ballistic armor plate **90** of this disclosure. According to certain non-limiting embodiments, the article of manufacture consists of or comprises a formed ballistic armor plate **90** in the form of one of a monolithic hull, a V-shaped hull, a blast protective vehicle underbelly (for protection from mines and other explosive devices), and an enclosure for blast protection.

[0096] Several examples illustrating certain non-limiting embodiments according to the present disclosure follow.

Example 1

[0097] An induction heating device was constructed in the form of an induction heating table. A photograph of the heating table is provided in FIG. **10**. A steel alloy plate having a thickness of 0.5 inch (1.27 cm) was used as the support and the ferrous alloy surface. Legs were welded to the steel plate to support the plate. A copper induction coil was positioned on the underside of the steel alloy plate and adapted to heat a lineal region of the steel alloy plate and thereby heat the ferrous alloy surface of the steel alloy plate. The induction coil was energized with an RF power transformer using a frequency suitable for heating of ferrous alloys such as the steel alloy of the steel alloy plate. The induction heating device may be used to conductively heat localized regions of metallic plates and other articles including hard-to-form metallic materials and other metallic materials. The conductively heated forms may then be bent or otherwise formed, for example, as discussed in connection with various embodiments herein.

Example 2

[0098] A plate of ATI 425 titanium alloy (Ti-4Al-2.5V-1.5Fe-0.25O_2 alloy, UNS R54250) having a thickness of 1 inch (2.54 cm) was obtained from ATI Wah Chang, Albany Oreg., an Allegheny Technologies Incorporated company. The plate was hot rolled via conventional mill practices and was received in mill-annealed condition. The plate was sawed into 12 inch by 30 inch samples. The induction heating table described in Example 1 was configured so that a localized lineal region of the ferrous alloy surface was inductively heated to a temperature of 800° F. (428° C.). The titanium alloy plate samples were sequentially positioned on the induction table so that an intended bend line of each sample was positioned over the heated localized region of the induction heating table, and a localized region of each sample was thereby conductively heated. More specifically, a lineal region of each sample, including an intended bend line and an immediately adjacent region, was conductively heated to 800° F. (428° C.) in about 12 minutes through contact with the ferrous alloy surface. Before any significant cooling could occur, the samples were bent along the heated bend line on a brake press located near the induction heating table. The samples were bent to increasing radii of 1 t through 6 t. The bent sample are shown in the photograph of FIG. **11**.

[0099] The bent samples were examined to assess the condition of the bend region of each sample. No surface defects, linear indications, or cracks were observed in the bend regions.

Example 3

[0100] An ATI 425® titanium alloy plate having a thickness of 1 inch (2.54 cm), in the same mill-annealed condition as used in Example 2, was obtained from ATI Wah Chang. The length and width of the plate were 100 inches (2.54 m) by 80 inches (2.032 m). The plate was positioned on the induction heating table described in Example 1, and a lineal region of the plate including an intended bend line and an adjacent region was conductively heated to 800° F. (426° C.) in about 20 minutes. The plate was transferred to a brake press before the heated lineal region of the plate experienced any significant cooling, and the plate was bent to a radius of 2 t along the bend line. The plate was positioned back on the induction heating table and arranged so that a different lineal region including another intended bend line was conductively heated to 850° F. (454.4° C.). The plate was then transferred to a brake press and bent along the bend line to a radius of 2 t before any significant cooling of the lineal region occurred. This process was repeated until the plate was bent to a 2 t radius at six different locations. No surface defects or cracking were observed in the six bend regions.

Example 4

[0101] A plate is formed using the process generally described in Example 3 to include one or more bends. The plate may be comprised of, for example, Ti-4Al-2.5V-1.5Fe-0.25O_2 alloy, another titanium alloy, or an armor alloy such as, for example, a 500 BHN steel armor alloy, a 600 BHN steel armor alloy, a 700 BHN steel armor alloy, a high strength low alloy steel, an RHA alloy, an HHA alloy, or a UHH alloy. The formed plate is welded to the chassis of an armored or other vehicle. The formed plate serves as a ballistic armor plate underbelly for the vehicle. The shape, orientation, and/or composition of the formed plate is adapted to dissipate blast energy generated by explosive devices detonated under the vehicle.

Example 5

[0102] A localized region of an 85-inch (215.9 cm) long, 1-inch (2.54 cm) thick ATI 425® titanium alloy plate was directly inductively heated using a non-limiting embodiment of a direct localized induction heating device as disclosed herein and as depicted in FIG. **6**. The induction heating device included a serpentine-shaped induction coil having six sections spaced in a plane about 3 inches (7.62 cm) apart and positioned about 0.5 inches (1.27 cm) from the refractory support, as depicted in FIG. **7**. The thickness of the refractory support was about 1 inch (2.54 cm). The induction coil was energized at 150 KW, 1 KHz, and 1A for 900 seconds. The power to the induction coil was then shut off, and the plate was allowed to air cool. The temperature of the top and bottom of the plate was measured after 900 seconds of localized induction heating and after 60 seconds of air cooling as a function of the distance from the center line of the heated zone. FIG. **12** contains a plot of the measured temperatures of the top and bottom of the plate after heating and after cooling for 60 seconds. The temperature of the top and bottom of the plate in the center region of the heated zone ranged from about 1200° F. (648.9° C.) to about 900° F. (482° C.) after 900 seconds of induction heating, and the heated zone extended about 11 inches (27.94 cm) on each side of the center line of the plate region that was to be bent. After cooling in ambient air for about 60 seconds, the temperature in the center region of the heated zone was in a range of about 900° F. (482° C.) to about 1000° F. (537.8° C.), which is in the temperature range at which the plate could be bent or otherwise formed.

[0103] It will be understood that the present description illustrates those aspects of the invention relevant to a clear understanding of the invention. Certain aspects that would be apparent to those of ordinary skill in the art and that, therefore, would not facilitate a better understanding of the invention have not been presented in order to simplify the present description. Although only a limited number of embodiments of the present invention are necessarily described herein, one of ordinary skill in the art will, upon considering the foregoing description, recognize that many modifications and variations of the invention may be employed. All such variations and modifications of the invention are intended to be covered by the foregoing description and the following claims.

1. A method of forming a metallic article, the method comprising:
- inductively heating a localized region of a metallic article to a forming temperature, wherein the forming temperature is in a forming temperature range of 0.20 to 0.50 of a melting temperature of the material; and
- forming the metallic article in the localized region.

2. The method of claim **1**, wherein forming the metallic article comprises at least one of bending, drawing, punching, stamping, and roll forming.

3. The method of claim **1**, wherein the metallic article comprises a material selected from a titanium alloy, a nickel-base alloy, a stainless steel alloy, a high-strength low-alloy steel, and an armor steel alloy.

4. The method of claim **1**, wherein the metallic article is selected from an ingot, a billet, a bloom, a round bar, a square bar, an extrusion, a tube, a pipe, a slab, a sheet, and a plate.

5. The method of claim **1**, wherein the metallic article is a plate, the localized region comprises a lineal region, and forming the metallic article comprises bending the metallic article in the lineal region.

6. The method of claim **1**, wherein the metallic article comprises a titanium alloy.

7. The method of claim **1**, wherein the metallic article comprises a material selected from the group consisting of ASTM Grades 5, 6,12, 19, 20, 21, 23, 24, 25, 29, 32, 35, 36, and 38 titanium alloys.

8. The method of claim **1**, wherein the metallic article comprises a specialty steel.

9. The method of claim **1**, wherein the metallic article comprises a material selected from a 500 BHN steel armor, a 600 BHN steel armor, a 700 BHN steel armor, a high strength low alloy steel, an RHA alloy, an HHA alloy, and a UHH alloy.

10. The method of claim **1**, wherein the metallic article comprises a nickel base alloy.

11. The method of claim **1**, wherein metallic article has a thickness of at least 0.125 inches (3.175 mm).

12. The method of claim **1**, wherein the metallic article has a thickness of at least 0.1875 inches (4.763 mm).

13. The method of claim **1**, wherein the metallic article comprises Ti-4Al-2.5V-1.5Fe-0.25O_2 titanium alloy (UNS 54250) and the forming temperature range is 728° F. to 874° F. (387° C. to 468° C.).

14. The method of claim **1**, wherein the metallic article comprises a titanium alloy and the forming temperature range is 700° F. to 900° F.

15. The method of claim **1**, wherein inductively heating the localized region comprises heating the localized region with at least one induction heater to a temperature in the forming temperature range.

16. The method of claim **1**, wherein forming the metallic article in the localized region comprises bending the metallic article in the localized region to a radius of at least 2 t.

17. The method of claim **1**, wherein forming the metallic article in the localized region comprises bending the metallic article in the localized region to a radius of at least 1 t.

18. The method of claim **1**, wherein after forming, the localized region of the metallic article is free of linear indications and cracks.

19. A method of bending a metallic plate, the method comprising:
- inductively heating a lineal region of a metallic plate to a bending temperature, wherein the bending temperature is in a bending temperature range of 0.2 to 0.5 of a melting temperature of the metallic plate; and
- bending the metallic plate in the lineal region.

20. The method of claim **19**, wherein the metallic plate comprises material selected from a titanium alloy, a nickel-base alloy, a stainless steel alloy, a high-strength low-alloy steel, and an armor steel alloy.

21. The method of claim **19** wherein the metallic plate comprises a titanium alloy.

22. The method of claim **19**, wherein the metallic plate comprises a material selected from the group consisting of ASTM Grades 5, 6, 12, 19, 20, 21, 23, 24, 25, 29, 32, 35, 36, and 38 titanium alloys.

23. The method of claim **19**, wherein the metallic plate comprises a specialty steel.

24. The method of claim **19**, wherein the metallic plate comprises a material selected from a 400 BHN steel armor, a 500 BHN steel armor, a 600 BHN steel armor, a 700 BHN steel armor, a high strength low alloy steel, an RHA alloy, an HHA alloy, and a UHH alloy.

25. The method of claim **19**, wherein the metallic plate has a thickness of at least 0.125 inches (3.175 mm).

26. The method of claim **19**, wherein the metallic plate has a thickness of at least 0.1875 inches (4.763 mm).

27. The method of claim **19**, wherein the metallic plate comprises Ti-4Al-2.5V-1.5Fe-0.25O_2 titanium alloy (UNS 54250) and the bending temperature range is 728° F. to 874° F. (387° C. to 468° C.).

28. The method of claim **19**, wherein the metallic plate comprises a titanium alloy and the bending temperature range is 700° F. to 900° F.

29. The method of claim **19**, wherein inductively heating the lineal region comprises heating the lineal region with at least one induction heater to a temperature in the bending temperature range.

30. The method of claim **19**, wherein bending the metallic plate in the lineal region comprises bending the metallic plate in the lineal region to a radius of at least 2 t.

31. The method of claim **19**, wherein bending the metallic plate in the lineal region comprises bending the metallic plate in the lineal region to a radius of at least 1 t.

32. The method of claim **19**, wherein after forming, the localized region of the metallic article is free of linear indications and cracks.

33. A method of forming a metallic material, the method comprising:
- placing a metallic article comprising a material selected from a metal and a metal alloy on a ferrous alloy surface;
- inductively heating a localized region of the ferrous alloy surface in contact with a localized region of the metallic article to a predetermined temperature and thereby conductively heating the localized region of the metallic article to a forming temperature within a forming temperature range; and
- forming the metallic article in the localized region of the metallic article.

34. The method of claim **33**, wherein the metallic article comprises a material selected from a titanium alloy, a nickel-base alloy, a stainless steel alloy, a high-strength low-alloy steel, and an armor steel alloy.

35. The method of claim **33**, wherein the forming temperature range is from 0.2 to 0.5 of a melting temperature of the metallic material.

36. The method of claim **33**, wherein the metallic article comprises a titanium alloy.

37. The method of claim **33**, wherein the metallic article comprises a material selected from the group consisting of ASTM Grades 5, 6, 12, 19, 20, 21, 23, 24, 25, 29, 32, 35, 36, and 38 titanium alloys.

38. The method of claim **33**, wherein the metallic article comprises a nickel base alloy.

39. The method of claim **3**, wherein the metallic article comprises a specialty steel.

40. The method of claim **33**, wherein the metallic article comprises a material selected from a 400 BHN steel armor, a 500 BHN steel armor, a 600 BHN steel armor, a 700 BHN steel armor, a high strength low alloy steel, an RHA alloy, an HHA alloy, and a UHH alloy.

41. The method of claim **33**, wherein the metallic article is a plate, the localized region comprises a lineal region, and forming the metallic article in the localized region comprises bending the plate in the lineal region.

42. The method of claim **33**, wherein the metallic article has a thickness of at least 0.125 inches (3.175 mm).

43. The method of claim **33**, wherein the metallic article has a thickness of at least 0.1875 inches (4.763 mm).

44. The method of claim **33**, wherein the metallic article comprises Ti-4Al-2.5V-1.5Fe-0.25O_2 titanium alloy (UNS 54250) and the forming temperature range is 728° F. to 874° F. (387° C. to 468° C.).

45. The method of claim **33**, wherein the metallic article comprises a titanium alloy and the forming temperature range is 700° F. to 900° F.

46. The method of claim **33**, wherein inductively heating the localized region of the ferrous alloy surface comprises heating the localized region of the ferrous alloy surface with at least one induction heater.

47. The method of claim **33**, wherein forming the metallic article in the localized region comprises bending the metallic article in the localized region to a radius of at least 2 t.

48. The method of claim **33**, wherein farming the metallic article in the localized region comprises bending the metallic article in the localized region to a radius of at least 1 t.

49. The method of claim **33**, wherein after forming, the localized region is free of linear indications and cracks.

50. The method of claim **33**, wherein the metallic article is selected from an ingot, a billet, a bloom, a round bar, a square bar, an extrusion, a tube, a pipe, a slab, a sheet, and a plate.

51. A method of bending a metallic plate, the method comprising:

placing a metallic plate comprising a material selected from a metal and a metal alloy on a ferrous alloy surface;

inductively heating a lineal region of the ferrous alloy surface in contact with a lineal region of the metallic plate to a predetermined temperature and thereby conductively heating the lineal region of the metallic plate to a bending temperature within a bending temperature range; and

bending the metallic plate in the lineal region of the metallic plate.

52. The method of claim **51**, wherein the bending temperature range is 0.2 to 0.5 of a melting temperature of the material.

53. The method of claim **51**, wherein the metallic plate comprises material selected from a titanium alloy, a nickel-base alloy, a stainless steel alloy, a high-strength low-alloy steel, and an armor steel alloy.

54. The method of claim **51**, wherein the metallic plate comprises a titanium alloy.

55. The method of claim **51**, wherein the metallic plate comprises a material selected from the group consisting of ASTM Grades 5, 6, 12, 19, 20, 21, 23, 24, 25, 29, 32, 35, 36, and 38 titanium alloys.

56. The method of claim **51**, wherein the metallic plate comprises a nickel base alloy.

57. The method of claim **51**, wherein the metallic plate comprises a specialty steel.

58. The method of claim **51**, wherein the metallic plate comprises a material selected from a 500 BHN steel armor, a 600 BHN steel armor, a 700 BHN armor, a high strength low alloy steel, an RHA alloy, an HHA alloy, and a UHH alloy.

59. The method of claim **51**, wherein the metallic plate has thickness of at least 0.125 inches (3.175 mm).

60. The method of claim **51** wherein the metallic plate has a thickness of at least 0.1875 inches (4.763 mm).

61. The method of claim **51**, wherein the metallic plate comprises Ti-4Al-2.5V-1.5Fe-0.25O_2 titanium alloy (UNS R54250) and the bending temperature range is 728° F. to 874° F. (387° C. to 468° C.).

62. The method of claim **51**, wherein the metallic plate comprises a titanium alloy and the bending temperature range is 700° F. to 900° F.

63. The method of claim **51**, wherein inductively heating the lineal region of the ferrous alloy surface comprises heating the lineal region of the ferrous alloy surface with at least one induction heater.

64. The method of claim **51**, wherein bending the metallic plate in the lineal region comprises bending the metallic plate in the lineal region to a bend radius of at least 2 t.

65. The method of claim **51**, wherein bending the metallic plate in the lineal region comprises bending the metallic plate in the lineal region to a bend radius of at least 1 t.

66. The method of claim **51**, wherein after bending the lineal region is free of linear indications and cracks.

67. A device for localized heating of a metallic article comprising a material selected from a metal and a metal alloy, the device comprising:

a support including a ferrous alloy surface; and

at least one induction heating device;

wherein the at least one induction heating device is positioned and adapted to inductively heat a localized region of the ferrous alloy surface, and

wherein the inductively heated localized region of the ferrous alloy surface is adapted to heat to a predetermined temperature a localized region of a metallic article comprising a material selected from a metal and a metal alloy that is positioned on the ferrous alloy surface.

68. The device of claim **67**, wherein the support comprises at least one of a ferrous alloy sheet including the ferrous alloy surface, and a ferrous alloy plate including the ferrous alloy surface.

69. The device of claim **67**, wherein the ferrous alloy surface comprises a steel alloy surface.

70. The device of claim **67**, wherein the ferrous alloy surface comprises one or more materials selected from carbon steel, a steel alloy, and a stainless steel.

71. The device of claim **67**, wherein the at least one induction heating device is tuned to inductively heat a predetermined localized region of the ferrous alloy surface.

72. The device of claim **67**, wherein the at least one induction heating device is positioned opposite the ferrous alloy surface and is adapted to inductively heat a predetermined lineal region of the ferrous alloy surface.

73. A device for localized heating of a metallic article comprising a material selected from a metal and a metal alloy, the device comprising:

a support including a support surface; and

at least one induction heating device:

wherein the at least one induction heating device is positioned and adapted to inductively heat a localized region of a metallic article positioned on the support surface to a predetermined temperature; and

wherein the support and the support surface comprise a material that is not heated by the at least one induction heating device.

74. The device of claim **73**, wherein the support and support surface comprise a refractory material.

75. The device of claim **73**, wherein the support and support surface comprises one or more of aluminum oxide, silicon oxide, aluminosilicate, magnesium oxide, zirconium oxide, calcium oxide, silicon carbide, fire clay, fire brick, magnesite ore, dolomite ore, and chrome ore.

76. The device of claim **73**, wherein a frequency of the at least one induction coil is tuned to heat of the material comprising the metallic article.

77. The device of claim **76**, wherein the specific metal alloy is a titanium alloy and the frequency of the induction coil is tuned to 1 KHz.

78. A system for bending a metallic article comprising a material selected from a metal and a metal alloy, the system comprising:

a heating device comprising

a support including a ferrous alloy surface, and

at least one induction heating device;

wherein the at least one induction heating device is positioned and adapted to inductively heat a predetermined lineal region of the ferrous alloy surface; and

wherein the inductively heated lineal region of the ferrous alloy surface is adapted to conductively heat a lineal region of a metallic article positioned on the ferrous alloy surface to a bending temperature in a bending temperature range; and

a metallic material bending apparatus positioned proximate the ferrous alloy surface and adapted to bend the metallic article in the lineal region before the lineal region cools below the bending temperature range.

79. A system for bending a metallic article comprising a material selected from a metal and a metal alloy, the system comprising:

a heating device comprising

a support including a support surface, and

at least one induction heating device;

wherein the at least one induction heating device is positioned and adapted to inductively heat a localized, region of a metallic article positioned on the support surface to a bending temperature in a bending temperature range; and

wherein the support and the support surface comprise a material that is not heated by the at least one induction heating device; and

a metallic material bending apparatus positioned proximate the support and the support surface and adapted to bend the metallic article in the lineal region before the lineal region cools below the bending temperature range.

80. A formed ballistic armor plate comprising:

at least one of a titanium alloy, a nickel-base alloy, and a specialty steel alloy, a stainless steel alloy, a high-strength low-alloy steel (HSLA), and an armor steel alloy; and

at least one bend region having a bend radius of at least 2 t.

81. The formed ballistic armor plate of claim **80**, wherein the formed ballistic armor plate has a thickness of at least 0.125 inches (3.175 mm).

82. The formed ballistic armor plate of claim **80**, wherein the formed ballistic armor plate has a thickness of at least 0.1875 inches (4.763 mm).

83. The formed ballistic armor plate of claim **80**, wherein the formed ballistic armor plate is one of a monolithic hull, a V-shaped hull, a blast protective vehicle underbelly, and an enclosure.

84. An article of manufacture comprising a formed ballistic armor plate according to any of claims **80** through **83**.

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