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(54) **Title:** ULTRA-HARD COLD-WORKED STEEL ALLOY

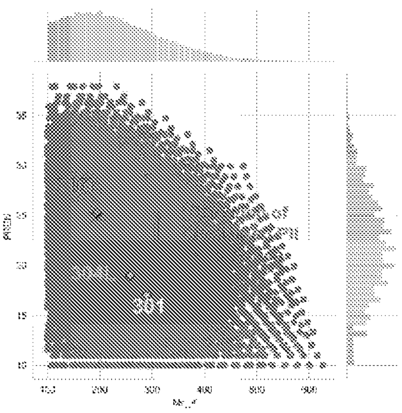

FIG. 1A

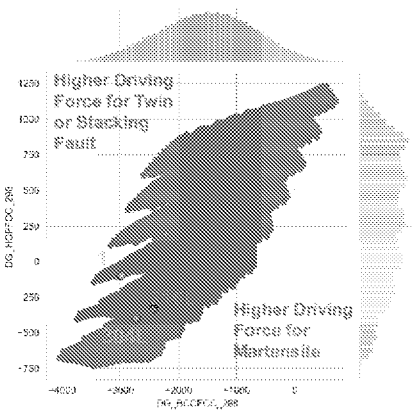

FIG. 1B

(57) **Abstract:** Embodiments relate to cold-worked steel alloys with improved strength, hardness and corrosion resistance useful for creating products, such as exterior vehicle body components. Processes for preparing cold-worked steel alloys are also described.

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ULTRA-HARD COLD-WORKED STEEL ALLOY

CROSS-REFERENCE TO RELATED APPLICATION

[0001] Any and all applications for which a foreign or domestic priority claim is identified in the Application Data Sheet as filed with the present application are hereby incorporated by reference under 37 CFR 1.57, and Rules 4.18 and 20.6. This application claims priority to U.S. Provisional Application No. 63/234,016, entitled ULTRA-HARD COLD-WORKED STEEL ALLOY, and filed on August 17, 2021, which is incorporated by reference in its entirety herein.

BACKGROUND

Field

[0002] The present invention relates to steel alloys. More specifically, the present invention relates to steel alloys with improved hardness and corrosion resistance for high-performance applications including automobile parts.

Description of the Related Art

[0003] There are many "stainless" steels that resist corrosion including a family of commercially produced "3xx" series stainless steel alloys. The most common of these alloys are 301, 304/304L, 316/316L and are commonly produced in a variety of product forms. There are also other stainless steel products that are differentiated based upon their microstructure and method of strength: Austenitic (3xx series), Martensitic (4xx series), Ferritic, Duplex, and precipitation hardenable (PH).

[0004] In order to increase hardness, martensitic steels generally require controlled heat treatments and quench cycles, sometimes including cryogenic treatments, to ensure full martensitic transformation and hardening of the alloy. However, such added treatments increase alloy costs, and heat treatments require expensive equipment and may cause warpage of the target product depending upon product form. Furthermore, corrosion resistant martensitic steels typically incorporate relatively high amounts of cobalt for corrosion resistance. However, cobalt is a costly material which increases the cost of using martensitic alloys.

SUMMARY

[0005] For purposes of summarizing the disclosure and the advantages achieved over the prior art, certain objects and advantages of the disclosure are described herein. Not all such objects or advantages may be achieved in any particular embodiment. Thus, for example, those skilled in the art will recognize that the invention may be embodied or carried out in a manner that achieves or optimizes one advantage or group of advantages as taught herein without necessarily achieving other objects or advantages as may be taught or suggested herein.

[0006] All of these embodiments are intended to be within the scope of the invention herein disclosed. These and other embodiments will become readily apparent to those skilled in the art from the following detailed description of the preferred embodiments having reference to the attached figures, the invention not being limited to any particular preferred embodiment(s) disclosed.

[0007] In one aspect, a steel alloy composition is described. The composition includes Fe, a hardness is at least about 400 HV, and an E_{pit}-E_{ocp} corrosion resistance of at least about 500 mV in a 3 wt% sodium chloride aqueous solution.

[0008] In some embodiments, the hardness is about 420 HV to about 500 HV. In some embodiments, the E_{pit}-E_{ocp} corrosion resistance is about 520 mV to about 800 mV. In some embodiments, the E_{pit}-E_{ocp} corrosion resistance is about 520 mV to about 600 mV. In some embodiments, the composition has a yield strength of at least about 1100 MPa. In some embodiments, the composition has a ductility of at least about 60° bend angle at 1.8mm thickness. In some embodiments, martensite formation begins at about 260 K to about 340 K. In some embodiments, martensite formation begins at about 260 K to about 320 K. In some embodiments, the composition has at least about 12 vol% martensite. In some embodiments, the composition has a yield strength of at least about 1100 MPa.

[0009] In some embodiments, the composition includes:

Cr: 15-18 wt.%;

Ni: 4-8 wt.%;

Mn: 1.5-6 wt.%;

Fe: Bal

[0010] In some embodiments, the composition further includes at most about 0.25 wt. % N. In some embodiments, the composition further includes at most about 2 wt. % Mo. In some embodiments, the composition further includes at most about 0.03 wt. % C, at most about 0.75 wt. % Si, at most about 0.045 wt. % P, and at most about 0.03 wt. % S.

[0011] In some embodiments, the composition includes:

C: at most about 0.03 wt.%;

N: 0.05-0.25 wt.%;

Cr: 15-18 wt.%;

Ni: 4-8 wt.%;

Mn: 1.5-6 wt.%;

Si: at most about 0.75 wt.%;

Mo: 0.5-2 wt.%;

P: at most about 0.045 wt.%;

S: at most about 0.03 wt.%; and

Fe: Bal.

[0012] In some embodiments, the composition includes:

Cu: at most about 0.5 wt.%;

Co: at most about 0.8 wt.%;

Al: at most about 0.03 wt.%;

Ti: at most about 0.03 wt.%; and

B: at most about 0.05 wt.%.

[0013] In some embodiments, the composition further includes at most about 0.05 wt.% of each of at least one additional element, and a total of at most about 0.15 wt.% of the at least one additional element.

[0014] In another aspect, a process for preparing an alloy is described. The process includes casting a steel alloy comprising Fe, performing a processing step on the steel alloy selected from the group consisting of hot-working, annealing, pickling and combinations thereof to form a processed steel alloy, and cold working the processed steel alloy to form a cold worked steel alloy with a hardness is at least about 400 HV and an E_{pit}-E_{ocp} corrosion resistance of at least about 500 mV in a 3 wt% sodium chloride aqueous solution.

[0015] In some embodiments, the processed steel alloy is cold-worked to a thickness reduction of at least about 30%. In some embodiments, the cold worked steel has a thickness of about 0.01 mm to about 4 mm. In some embodiments, the cold worked steel has a thickness of about 1 mm to about 4 mm. In some embodiments, the process further includes machining the cold worked steel. In some embodiments, hot-working is performed prior to annealing the steel alloy. In some embodiments, annealing is performed prior to hot-working the steel alloy. In some embodiments, processing the steel alloy is performed prior to cold-working the steel alloy the processed steel alloy.

[0016] In another aspect, a vehicle comprising a vehicle body comprising the steel alloy composition is described. In some embodiments, the vehicle body comprises an exterior vehicle body, and the exterior vehicle body comprises the steel alloy. In some embodiments, the steel alloy is uncoated. In some embodiments, a corrosion protective agent is not disposed over the steel alloy. In some embodiments, the corrosion protective agent is paint. In some embodiments, the vehicle is an electric vehicle comprising an electric motor.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] FIG. 1A shows computational results of steel alloys for corrosion resistance in pitting resistance equivalent number (PREN) versus martensite formation start temperature (Ms).

[0018] FIG. 1B shows computational results of steel alloys for the driving force comparison between FCC, BCC and HCP.

[0019] FIG. 2A shows computational results of steel alloys A4, A7 and A8 for corrosion resistance in pitting resistance equivalent number (PREN) versus martensite formation start temperature (Ms).

[0020] FIG. 2B shows computational results of steel alloys A4, A7 and A8 for the driving force comparison between FCC, BCC and HCP.

[0021] FIG. 2C shows computational results of Alloys 1-7 for corrosion resistance in pitting resistance equivalent number (PREN) versus martensite formation start temperature (Ms).

[0022] FIG. 3 shows an Ashby Plot of computed hardness versus corrosion resistance of steel alloys A4, A7 and A8 shown against the actual respective values for commercial steel alloys.

[0023] FIGS. 4A and 4B show optical micrographs of an A4 alloy prepared at a 50lb scale cold-worked to 24% reduction.

[0024] FIGS. 5A and 5B show optical micrographs of an A4 alloy prepared at a 50lb scale cold-worked to 36% reduction.

[0025] FIGS. 6A and 6B show optical micrographs of an A4 alloy prepared at a 50lb scale cold-worked to 44% reduction.

[0026] FIGS. 7A and 7B show optical micrographs of an A4 alloy prepared at a 50lb scale cold-worked to 56% reduction.

[0027] FIG. 8 shows the experimentally measured hardness, strength and elongation properties of A4, A7 and A8 alloys prepared at a 50kg scale.

[0028] FIG. 9 shows the longitudinal stress-strain experimental data for an A4 alloy prepared at a 50kg scale cold-worked to various degrees.

[0029] FIG. 10 shows the longitudinal stress-strain experimental data for an A7 alloy prepared at a 50kg scale cold-worked to various degrees.

[0030] FIG. 11 shows the longitudinal stress-strain experimental data for an A8 alloy prepared at a 50kg scale cold-worked to various degrees.

[0031] FIG. 12A shows an optical micrograph of a cold-worked A4 alloy prepared at a 50kg scale.

[0032] FIG. 12B shows an optical micrograph of a cold-worked A7 alloy prepared at a 50kg scale.

[0033] FIG. 12C shows an optical micrograph of a cold-worked A8 alloy prepared at a 50kg scale.

[0034] FIG. 13A shows the experimental results of E_{pit}-E_{ocp} corrosion resistance of A4 alloy and A7 alloy.

[0035] FIG. 13B shows the experiment results of corrosion current density I_{corr} of A4 alloy and A7 alloy.

[0036] FIG. 14A shows the experimental results of E_{pit}-E_{ocp} corrosion resistance of A4, A7, B1, B2 and B3.

[0037] FIG. 14B shows the experimental results of corrosion current density I_{corr} of A4, A7, B1, B2 and B3 alloys.

[0038] FIG. 15A shows the experimental results of E_{pit}-E_{ocp} corrosion resistance of A4, A7, B1, B2 and B3 alloys versus corrosion resistance in pitting resistance equivalent number (PREN).

[0039] FIG. 15B shows the experimental results of corrosion current density I_{corr} of A4, A7, B1, B2 and B3 alloys versus corrosion resistance in pitting resistance equivalent number (PREN).

[0040] FIG. 16A shows the experimental results of E_{pit}-E_{ocp} corrosion resistance of Alloy 1, Alloy 2 and Alloy 4.

[0041] FIG. 16B shows the experimental results of corrosion current density I_{corr} of Alloy 1, Alloy 2 and Alloy 4.

[0042] FIG. 17 shows the experimental results of longitudinal and transverse bend angles of Alloy 1 compared to Type 301 stainless steel.

[0043] FIG. 18 shows the stress-strain experimental data for A4 alloy.

DETAILED DESCRIPTION

[0044] The present disclosure may be understood by reference to the following detailed description. It is noted that, for purposes of illustrative clarity, certain elements in various drawings may not be drawn to scale, may be represented schematically or conceptually, or otherwise may not correspond exactly to certain physical configurations of embodiments.

[0045] Embodiments relate to "cold-worked" (e.g., cold-rolled) steel alloys with improved strength, hardness and corrosion resistance useful for creating products, such as exterior vehicle body components. Such cold-worked steel alloys may allow the exterior facing vehicle body components to be resistant to denting, scratching, and pitting while avoiding the need for a corrosion protective agent (e.g., paint) over the exterior vehicle body components. Cold working (e.g., cold-rolling) strengthens the disclosed steel alloy in part due to strain-induced martensitic phase transformation of the austenitic matrix, which imparts improved hardness and strength for scratch and dent resistance. Advantageously, the phase transformation of the disclosed steel alloy was found to have increased hardness and strength while maintaining corrosion resistance.

[0046] One embodiment is a cold-worked steel alloy having a hardness of at least about 400 HV and an E_{pit}-E_{ocp} corrosion resistance in a 3 wt% sodium chloride aqueous solution of at least about 500 mV. In some embodiments, the cold-worked steel alloy has a yield strength of at least about 1150 MPa, a hardness of at least about 420 HV or 43 HRC, a bend angle of at least about 60° at 1.8 mm thickness, and an E_{pit}-E_{ocp} corrosion resistance in a 3 wt% sodium chloride aqueous solution of at least about 500 mV. In some embodiments, the cold-worked steel alloy has a yield strength of at least about 1100 MPa, a hardness of at least about 420 HV or 43 HRC, a bend angle of at least about 60° at 1.6 mm thickness, and an E_{pit}-E_{ocp} corrosion resistance in a 3 wt% sodium chloride aqueous solution of at least about 520 mV. In some embodiments, a cold-worked steel alloy has a yield strength of about 1200 MPa, a hardness of at least about 45 HRC, a bend angle of at least about 65° at 1.8 mm thickness, and an E_{pit}-E_{ocp} corrosion resistance in a 3 wt% sodium chloride aqueous solution of at least about 530 mV.

[0047] Another embodiment is a cold-worked steel alloy having a hardness of at least about 400 HV and an E_{pit}-E_{ocp} corrosion resistance in a 3 wt% sodium chloride aqueous solution of at least about 500 mV. In some embodiments, the cold-worked steel alloy has a yield strength of at least about 1100 MPa, a hardness of at least about 420 HV or 43 HRC, a bend angle of at least about 60° at 1.6 mm thickness, and an E_{pit}-E_{ocp} corrosion resistance in a 3 wt% sodium chloride aqueous solution of at least about 520 mV. In some embodiments, a cold-worked steel alloy has a yield strength of about 1200 MPa, a hardness of at least about 45 HRC, a bend angle of at least about 65° at 1.8 mm thickness, and an E_{pit}-E_{ocp} corrosion resistance in a 3 wt% sodium chloride aqueous solution of at least about 530 mV.

Steel Alloy Compositions

[0048] The steel alloys disclosed herein were found to have improved hardness and corrosion resistance when cold-worked. In some embodiments, the steel alloy is a stainless steel alloy. The steel alloys are described herein by the weight percent (wt %) of the total elements and particles within the alloy, as well as specific properties of the alloys. It will be understood that the remaining composition of any alloy described herein includes iron (Fe) and incidental impurities.

[0049] Impurities may be present in the starting materials or introduced in one of the processing and/or manufacturing steps to create the steel alloy. Incidental impurities are compounds and/or elements that do not or do not substantially affect the material properties of the composition, such as hardness, corrosion resistance, yield strength, tensile strength, ductility, martensite formation and/or ferrite formation. In some embodiments, the total incidental impurities or other elements are, are about, are at most, or are at most about, 1 wt.%, 0.8 wt.%, 0.5 wt.%, 0.2 wt.% 0.15 wt.%, 0.1 wt.%, 0.05 wt.% or 0.01 wt.%, or any range of values therebetween. In some embodiments, each elemental incidental impurity or each additional element that is not recited is, is about, is at most, or is at most about, 0.8 wt.%, 0.5 wt.%, 0.2 wt.% 0.1 wt.%, 0.05 wt.%, 0.01 wt.%, 0.005 wt.% or 0.001 wt.%, or any range of values therebetween.

[0050] In some embodiments, the steel alloy includes incorporation of nitrogen at least in part for corrosion resistance and hardening properties. In some embodiments, the steel alloy includes chromium at least in part for corrosion resistance and strain-induced martensite transition properties. In some embodiments, the steel alloy includes nickel at least in part for toughness and tailored austenite stability properties. In some embodiments, the steel alloy includes manganese at least in part for austenite stability, cost effectiveness and stacking fault energy tuning properties. In some embodiments, the steel alloy includes molybdenum at least in part for corrosion resistance and hardening properties, and for enabling low carbon content for enhanced corrosion resistance.

[0051] In some embodiments, the steel alloy composition comprises C of at most, or of at most about, 0.03 wt %, N in the range of, or of about, 0.05-0.25 wt %, Cr in the range of, or of about, 15-18 wt %, Ni in the range of, or of about, 4-8 wt %, Mn in the range of, or of about, 1.5-6 wt %, Si of at most, or of at most about, 0.75 wt %, Mo in the range of, or of about, 0.5-2 wt %, P of at most, or of at most about, 0.045 wt %, S of at most, or of at most about, 0.03 wt %, with the remaining composition (by wt %) being Fe and incidental impurities. In some embodiments, the steel alloy composition comprises C of at most, or of at most about, 0.03 wt %, N in the range of, or of about, 0.15-0.25 wt %, Cr in the range of, or of about, 16-18 wt %, Ni in the range of, or of about, 5-6 wt %, Mn in the range of, or of about, 1.5-2.5 wt %, Si of at most, or of at most about, 0.75 wt %, Mo in the range of, or of about, 1-2 wt %, P of at most, or of at most about, 0.045 wt %, S of at most, or of at most about, 0.03

wt %, with the remaining composition (by wt %) being Fe and incidental impurities. In some embodiments, the steel alloy composition comprises C of at most, or of at most about, 0.03 wt %, N in the range of, or of about, 0.15-0.25 wt %, Cr in the range of, or of about, 16-18 wt %, Ni in the range of, or of about, 5-6 wt %, Mn in the range of, or of about, 1.5-3.0 wt %, Si of at most, or of at most about, 0.75 wt %, Mo in the range of, or of about, 1-2 wt %, P of at most, or of at most about, 0.045 wt %, S of at most, or of at most about, 0.03 wt %, with the remaining composition (by wt %) being Fe and incidental impurities. In some embodiments, the steel alloy composition comprises C of at most, or of at most about, 0.03 wt %, N in the range of, or of about, 0.05-0.15 wt %, Cr in the range of, or of about, 15-17 wt %, Ni in the range of, or of about, 6-8 wt %, Mn in the range of, or of about, 1.5-2.5 wt %, Si of at most, or of at most about, 0.75 wt %, Mo in the range of, or of about, 0.5-1.5 wt %, P of at most, or of at most about, 0.045 wt %, S of at most, or of at most about, 0.03 wt %, with the remaining composition (by wt %) being Fe and incidental impurities. In some embodiments, the steel alloy composition comprises C of at most, or of at most about, 0.03 wt %, N in the range of, or of about, 0.05-0.15 wt %, Cr in the range of, or of about, 15-17 wt %, Ni in the range of, or of about, 4-6 wt %, Mn in the range of, or of about, 4-6 wt %, Si of at most, or of at most about, 0.75 wt %, Mo in the range of, or of about, 0.75-1.5 wt %, P of at most, or of at most about, 0.045 wt %, S of at most, or of at most about, 0.03 wt %, with the remaining composition (by wt %) being Fe and incidental impurities. In some embodiments, the steel alloy composition comprises C of at most, or of at most about, 0.03 wt %, N in the range of, or of about, 0.11 wt %, Cr in the range of, or of about, 16 wt %, Ni in the range of, or of about, 6 wt %, Mn in the range of, or of about, 2 wt %, Si of at most, or of at most about, 0.75 wt %, Mo in the range of, or of about, 1.2 wt %, P of at most, or of at most about, 0.045 wt %, S of at most, or of at most about, 0.03 wt %, with the remaining composition (by wt %) being Fe and incidental impurities. In some embodiments, the steel alloy composition comprises C of at most, or of at most about, 0.03 wt %, N in the range of, or of about, 0.12 wt %, Cr in the range of, or of about, 13 wt %, Ni in the range of, or of about, 4 wt %, Mn in the range of, or of about, 6 wt %, Si of at most, or of at most about, 0.75 wt %, Mo in the range of, or of about, 2 wt %, P of at most, or of at most about, 0.045 wt %, S of at most, or of at most about, 0.03 wt %, with the remaining composition (by wt %) being Fe and incidental impurities. In some embodiments, the steel alloy composition comprises C of at most, or of at most about, 0.03 wt %, N in the range of, or of about, 0.05-0.15 wt %, Cr in the range of, or of about, 10-15 wt %, Ni in the range of, or of about, 3.5-4.5 wt %, Mn in the range of, or of about, 4-6 wt %, Si of at most, or of at most about, 0.75 wt %, Mo in the range of, or of about, 1.5-2.5 wt %, P of at most, or of at most about, 0.045 wt %, S of at most, or of at most about, 0.03 wt %, with the remaining composition (by wt %) being Fe and incidental impurities. In some embodiments, the steel alloy composition comprises C of at most, or of at most about, 0.03 wt %, N in the range of, or of about, 0.1 wt %, Cr in the range of, or of about, 11 wt %, Ni in the range of, or of about, 4 wt %, Mn in the range of, or of about, 6 wt %, Si of at most, or of at most about, 0.75 wt %, Mo in the range of, or of about, 1.0 wt %, P of at most, or of at most about, 0.045 wt %, S of at most, or of at most about, 0.03 wt %, with the remaining composition (by wt %) being Fe and incidental impurities. In some embodiments, the steel alloy composition comprises C of at most, or of at most about, 0.03 wt %, N in the range of, or of about, 0.05-0.15 wt %, Cr in the range of, or of about, 10-15 wt %, Ni in the range of, or of about, 3.5-4.5 wt %, Mn in the range of, or of about, 4-6 wt %, Si of at most, or of at most about, 0.75 wt %, Mo in the range of, or of about, 0.5-1.5 wt %, P of at most, or of at most about, 0.045 wt %, S of at most, or of at most about, 0.03 wt %, with the remaining composition (by wt %) being Fe and incidental impurities. In some embodiments, the steel alloy composition comprises C of at most, or of at most about, 0.03 wt %, N in the range of, or of about, 0.15 wt %, Cr in the range of, or of about, 16 wt %, Ni in the range of, or of about, 5.5 wt %, Mn in the range of, or of about, 2.7 wt %, Si of at most, or of at most about, 0.75 wt %, Mo in the range of, or of about, 1.25 wt %, P of at most, or of at most about, 0.045 wt %, S of at most, or of at most about, 0.03 wt %, with the remaining composition (by wt %) being Fe and incidental impurities. In some embodiments the maximum incidental impurities or other elements total, total about, total at most, or total at most about, 0.15 or 0.1 wt %. In some embodiments, each elemental incidental impurity or each other element is, is about, is at most, or is at most about 0.05 wt %.

[0052] In some embodiments, the steel alloy composition comprises carbon (C) in an amount of, of about, of at least, of at least about, of at most, or of at most about, 0.1 wt.%, 0.05 wt.%, 0.04 wt.%, 0.03 wt.%, 0.02 wt.%, 0.01 wt.% or 0.005 wt.%, or any range of values therebetween. In some embodiments, the steel alloy composition comprises nitrogen (N) in an amount of, of about, of at least, of at least about, of at most, or of at most about, 1 wt.%, 0.5 wt.%, 0.25 wt.%, 0.2 wt.%, 0.15 wt.%, 0.12 wt.%, 0.11 wt.%, 0.1 wt.%, 0.05 wt.% or 0.01

wt.%, or any range of values therebetween. In some embodiments, the steel alloy composition comprises chromium (Cr) in an amount of, of about, of at least, of at least about, of at most, or of at most about, 25 wt.%, 20 wt.%, 19 wt.%, 18 wt.%, 17 wt.%, 16 wt.%, 15 wt.%, 14 wt.%, 13 wt.%, 12 wt.%, 11 wt.%, or 10 wt.%, or any range of values therebetween. In some embodiments, the steel alloy composition comprises nickel (Ni) in an amount of, of about, of at least, of at least about, of at most, or of at most about, 15 wt.%, 10 wt.%, 9 wt.%, 8 wt.%, 7 wt.%, 6 wt.%, 5.5 wt.%, 5 wt.%, 4 wt.%, 3 wt.%, 2 wt.%, 1 wt.% or 0.5 wt.%, or any range of values therebetween. In some embodiments, the steel alloy composition comprises manganese (Mn) in an amount of, of about, of at least, of at least about, of at most, or of at most about, 15 wt.%, 10 wt.%, 9 wt.%, 8 wt.%, 7 wt.%, 6 wt.%, 5 wt.%, 4 wt.%, 3 wt.%, 2.7 wt.%, 2.5 wt. %, 2 wt.%, 1.5 wt.%, 1 wt.%, 0.5 wt.% or 0.1 wt.%, or any range of values therebetween. In some embodiments, the steel alloy composition comprises Silicon (Si) in an amount of, of about, of at least, of at least about, of at most, or of at most about, 2 wt.%, 1 wt.%, 0.9 wt.%, 0.8 wt.%, 0.75 wt.%, 0.7 wt.%, 0.65 wt.%, 0.6 wt.%, 0.55 wt.%, 0.5 wt.%, 0.4 wt.%, 0.3 wt.%, 0.2 wt.%, 0.1 wt.% or 0.05 wt.%, or any range of values therebetween. In some embodiments, the steel alloy composition comprises molybdenum (Mo) in an amount of, of about, of at least, of at least about, of at most, or of at most about, 5 wt.%, 4 wt.%, 3 wt.%, 2 wt.%, 1.7 wt.%, 1.5 wt.%, 1.4 wt.%, 1.25 wt.%, 1.2 wt.%, 1 wt.%, 0.9 wt.%, 0.8 wt.%, 0.75 wt.%, 0.7 wt.%, 0.6 wt.%, 0.5 wt.%, 0.4 wt.%, 0.3 wt.% 0.2 wt.%, 0.1 wt.% or 0.05 wt.%, or any range of values therebetween. In some embodiments, the steel alloy composition comprises phosphorus (P) in an amount of, of about, of at least, of at least about, of at most, or of at most about, 1 wt.%, 0.5 wt.%, 0.1 wt.%, 0.08 wt.%, 0.07 wt.%, 0.06 wt.%, 0.05 wt.%, 0.045 wt.%, 0.04 wt.%, 0.03 wt.%, 0.02 wt.%, 0.01 wt.% or 0.005 wt.%, or any range of values therebetween. In some embodiments, the steel alloy composition comprises sulfur (S) in an amount of, of about, of at least, of at least about, of at most, or of at most about, 1 wt.%, 0.5 wt.%, 0.1 wt.%, 0.08 wt.%, 0.07 wt.%, 0.06 wt.%, 0.05 wt.%, 0.045 wt.%, 0.04 wt.%, 0.03 wt.%, 0.02 wt.%, 0.01 wt.% or 0.005 wt.%, or any range of values therebetween. In some embodiments, the steel alloy composition comprises copper (Cu) in an amount of, of about, of at least, of at least about, of at most, or of at most about, 2 wt.%, 1 wt.%, 0.9 wt.%, 0.8 wt.%, 0.7 wt.%, 0.6 wt.%, 0.5 wt.%, 0.4 wt.%, 0.3 wt.%, 0.2 wt.%, 0.1 wt.%, 0.08 wt.%, 0.07 wt.%, 0.06 wt.%, 0.05 wt.%, 0.045 wt.%, 0.04 wt.%, 0.03 wt.%, 0.02 wt.%, 0.01 wt.% or 0.005 wt.%, or any range of values therebetween. In some embodiments, the steel alloy composition comprises cobalt (Co) in an amount of, of about, of at least, of at least about, of at most, or of at most about, 2 wt.%, 1 wt.%, 0.9 wt.%, 0.8 wt.%, 0.7 wt.%, 0.6 wt.%, 0.5 wt.%, 0.4 wt.%, 0.3 wt.%, 0.2 wt.%, 0.1 wt.%, 0.08 wt.%, 0.07 wt.%, 0.06 wt.%, 0.05 wt.%, 0.045 wt.%, 0.04 wt.%, 0.03 wt.%, 0.02 wt.%, 0.01 wt.% or 0.005 wt.%, or any range of values therebetween. In some embodiments, the steel alloy composition comprises aluminum (Al) in an amount of, of about, of at least, of at least about, of at most, or of at most about, 1 wt.%, 0.5 wt.%, 0.1 wt.%, 0.08 wt.%, 0.07 wt.%, 0.06 wt.%, 0.05 wt.%, 0.045 wt.%, 0.04 wt.%, 0.03 wt.%, 0.02 wt.%, 0.01 wt.% or 0.005 wt.%, or any range of values therebetween. In some embodiments, the steel alloy composition comprises titanium (Ti) in an amount of, of about, of at least, of at least about, of at most, or of at most about, 1 wt.%, 0.5 wt.%, 0.1 wt.%, 0.08 wt.%, 0.07 wt.%, 0.06 wt.%, 0.05 wt.%, 0.045 wt.%, 0.04 wt.%, 0.03 wt.%, 0.02 wt.%, 0.01 wt.% or 0.005 wt.%, or any range of values therebetween. In some embodiments, the steel alloy composition comprises boron (B) in an amount of, of about, of at least, of at least about, of at most, or of at most about, 1 wt.%, 0.5 wt.%, 0.1 wt.%, 0.08 wt.%, 0.07 wt.%, 0.06 wt.%, 0.05 wt.%, 0.045 wt.%, 0.04 wt.%, 0.03 wt.%, 0.02 wt.%, 0.01 wt.% or 0.005 wt.%, or any range of values therebetween. In some embodiments, the steel alloy composition comprises each elemental incidental impurity or each additional element not listed in an amount of, of about, of at most, or of at most about, 0.1 wt.%, 0.07 wt.%, 0.05 wt.%, 0.04 wt.%, 0.03 wt.%, 0.02 wt.%, 0.01 wt.% or 0.005 wt.%, or any range of values therebetween. In some embodiments, the steel alloy composition comprises a maximum incidental impurities or additional element total in an amount of, of about, of at most, or of at most about, 1 wt.%, 0.5 wt.%, 0.3 wt.%, 0.2 wt.%, 0.15 wt.%, 0.1 wt.%, 0.07 wt.%, 0.05 wt.%, 0.04 wt.%, 0.03 wt.%, 0.02 wt.%, 0.01 wt.% or 0.005 wt.%, or any range of values therebetween.

[0053] In some embodiments, the steel alloy composition comprises martensite in an amount of, of about, of at least, of at least about, of at most, or of at most about, 50 vol.%, 40 vol.%, 30 vol.%, 25 vol.%, 20 vol.%, 18 vol.%, 16 vol.%, 15 vol.%, 14 vol.%, 13 vol.%, 12 vol.%, 11 vol.%, 10 vol.%, 8 vol.% or 5 vol.%, or any range of values therebetween. In some embodiments, the steel alloy composition comprises ferrite in an amount of, of about, of at least, of at least about, of at most, or of at most about, 50 vol.%, 40 vol.%, 30 vol.%, 25 vol.%, 20 vol.%, 18 vol.%, 16 vol.%, 15 vol.%, 14 vol.%, 13 vol.%, 12 vol.%, 11 vol.%, 10 vol.%, 8 vol.% or 5 vol.%, or any range of values therebetween.

[0054] Computational survey space for steel alloys with wt.% Fe-Cr-Ni-Mo-Mn-C-N-0.75Si were performed and shown in FIGS. 1A and 1B, wherein FIG. 1A shows computational results for corrosion resistance in pitting resistance equivalent number (PREN) v. martensite formation start temperature (Ms), and FIG. 1B shows computational results for the driving force comparison between FCC, BCC and HCP. Using the computational survey space, steel alloy compositional ranges with predicted martensite formation temperature ranges and pitting resistance equivalent number (PREN) are shown below in Table 1 for steel alloys A1-A8.

Table 1

Alloy	Fe	C	N	Cr	Ni	Mn	Si	Mo	P	S	Ms[K]	PERN
A1	Bal.	0.03 Max	0.10-0.2	16-17	6-7	1.5-2.5	0.75 Max	1-2	0.045 Max	0.03 Max	240-340	20.9-26.9
A2	Bal.	0.03 Max	0.05-0.15	13-15	5-6	6-8	0.75 Max	2-3	0.045 Max	0.03 Max	169-286	21.2-25.5
A3	Bal.	0.03 Max	0.25-0.35	15.0-17.0	4.5-5.5	1.5-2.5	0.75 Max	0.5-1.5	0.045 Max	0.03 Max	236-348	23.1-25.1
A4	Bal.	0.03 Max	0.15-0.25	16-18	5-6	1.5-2.5	0.75 Max	1.0-2.0	0.045 Max	0.03 Max	257-340	22.5-27.8
A5	Bal.	0.03 Max	0.05-0.15	17-19	7-9	4-6	0.75 Max	0.5-1.5	0.045 Max	0.03 Max	100-244	22.9-23.9
A6	Bal.	0.03 Max	0	13-14	4-5	5-7	0.75 Max	0.75-1.25	0.045 Max	0.03 Max	294-349	16.3-17.3
A7	Bal.	0.03 Max	0.05-0.15	15-17	6-8	1.5-2.5	0.75 Max	0.5-1.5	0.045 Max	0.03 Max	247-352	19.9-21.9
A8	Bal.	0.03 Max	0.05-0.15	15-17	4-6	4-6	0.75 Max	0.75-1.5	0.045 Max	0.03 Max	200-359	19.9-21.9

[0055] FIGS. 2A and 2B show computational results for corrosion resistance in pitting resistance equivalent number (PREN) v. martensite formation start temperature (Ms) and the driving force comparison between FCC, BCC and HCP, respectively, for alloys A4, A7 and A8. FIG. 2C shows computational results for corrosion resistance in pitting resistance equivalent number (PREN) v. martensite formation start temperature (Ms), respectively, for A4 (i.e., Alloy 1), A7 (i.e., Alloy 2), A 8 (i.e., Alloy 3), B1 (i.e., Alloy 4), B2 (i.e., Alloy 5), B3 (i.e., Alloy 6) and A4(2) (i.e., Alloy 7). Steel alloy compositional ranges for alloys A4 (i.e., Alloy 1), A7 (i.e., Alloy 2), A 8 (i.e., Alloy 3), B1 (i.e., Alloy 4), B2 (i.e., Alloy 5), B2(2), B3 (i.e., Alloy 6), B3(2), A4(2) (i.e., Alloy 7) and A4(3) are shown below in Table 2.

Table 2

Alloy	Alloy ID	Fe	C	N	Cr	Ni	Mn	Si	Mo	P	S
A4	Alloy 1	Bal.	0.03 Max	0.15-0.25	16-18	5-6	1.5-2.5	0.75 Max	1.0-2.0	0.045 Max	0.03 Max
A7	Alloy 2	Bal.	0.03 Max	0.05-0.15	15-17	6-8	1.5-2.5	0.75 Max	0.5-1.5	0.045 Max	0.03 Max
A8	Alloy 3	Bal.	0.03 Max	0.05-0.15	15-17	4-6	4-6	0.75 Max	0.75-1.5	0.045 Max	0.03 Max
B1	Alloy 4	Bal.	0.03 Max	0.11	16	6	2	0.75 Max	1.2	0.045 Max	0.03 Max
B2	Alloy 5	Bal.	0.03 Max	0.12	13	4	6	0.75 Max	2.0	0.045 Max	0.03 Max
B2(2)	/	Bal.	0.03 Max	0.05-0.15	10-15	3.5-4.5	4-6	0.75 Max	1.5-2.5	0.045 Max	0.03 Max
B3	Alloy 6	Bal.	0.03 Max	0.1	11	4	6	0.75 Max	1.0	0.045 Max	0.03 Max
B3(2)	/	Bal.	0.03 Max	0.05-0.15	10-15	3.5-4.5	4-6	0.75 Max	0.5-1.5	0.045 Max	0.03 Max
A4(2)	Alloy 7	Bal.	0.03 Max	0.15	16	5.5	2.7	0.75 Max	1.25	0.045 Max	0.03 Max
A4(3)	/	Bal.	0.03 Max	0.15-0.25	16-18	5-6	1.5-3.0	0.75 Max	1.0-2.0	0.045 Max	0.03 Max

[0056] FIG. 3 shows an Ashby Plot of computed hardness v. corrosion resistance of steel alloys A4, A7 and A8 shown against the actual respective values for commercial steel alloys. As shown in FIG. 3, alloys A4, A7 and A8 are computed to approach of or be above a hardness of 420 HV and corrosion resistance of 304L/316L commercial alloys.

Steel Alloy Crystalline Properties

[0057] In some embodiments, the steel alloy is an austenitic steel in the O temper, annealed condition. Through work hardening, strain-induced martensite may be formed. The degree to which the strain-induced martensite is formed may be owed to the austenite stability of the alloy at the conditions of cold working, including temperature and pressure. In some embodiments, as more strain-induced martensite is formed the alloy may become harder, increases in ferromagnetic character, improves the corrosion resistance and/or improves the strength of the material.

[0058] In some embodiments, the steel alloys form martensite crystalline structures at, at about, at least, at least about, at most, or at most about, 500K, 450K, 400K, 350K, 340K, 330K, 320K, 310K, 300K, 290K, 289K, 280K, 270K, 260K, 250K, 240K, 220K, 200K or 150K, or any range of values therebetween.

Alloy Hardness

[0059] Alloy hardness may be controlled to impart scratch resistance, and to maintain a certain level of pit resistance and environmental resistance to the alloy. Hardness of an alloy may be given and/or calculated according to various scales. In some embodiments, hardness is given in the Rockwell scale (e.g. HRC). In some embodiments, hardness is given in Vickers scale (i.e. HV).

[0060] In some embodiments, the steel alloy has a hardness of, of about, of at least, of at least about, of at most, or of at most about, 35 HRC, 40 HRC, 41 HRC, 42 HRC, 43 HRC, 44 HRC, 45 HRC, 46 HRC, 47 HRC, 48 HRC, 49 HRC, 50 HRC, 52 HRC, 55 HRC or 60 HRC, or any range of values therebetween. In some embodiments, the steel alloy has a hardness of, of about, of at least, of at least about, of at most, or of at most about, 350 HV, 370 HV, 375 HV, 380 HV, 390 HV, 400 HV, 410 HV, 420 HV, 430 HV, 450 HV, 475 HV or 500 HV, or any range of values therebetween.

Corrosion/Oxidation Resistance

[0061] The cold-worked steel alloys are expected to last within punishing environments, such as those used in automotive applications where the automotive vehicle is subjected to extreme hot and cold environments. In some embodiments, the steel alloys are resistant to corrosion and/or oxidation, which improves environmental and/or dissolution resistance. Corrosion resistance of an alloy may be given and/or according to various scales or relative to other known alloys. In some embodiments, corrosion resistance is given in the pitting resistance equivalent number (PREN) scale. In some embodiments, corrosion resistance is given as the difference between critical pitting potential (E_{pit}) and the open-circuit potential (E_{ocp}) in a 3 wt% sodium chloride aqueous solution. In some embodiments, the pitting potentials are measured against a saturated calomel electrode (SCE).

[0062] In some embodiments, the corrosion resistance of the steel alloy is, is about, is at least, or is at least about, as much as a 304L alloy or a 316L alloy. In some embodiments, the corrosion resistance of the steel alloy is, is about, is at least, or is at least about, 15 PREN, 18 PREN, 20 PREN, 21 PREN, 22 PREN, 23 PREN, 24 PREN, 25 PREN, 26 PREN, 27 PREN, 28 PREN, 29 PREN, 30 PREN, 32 PREN, 35 PREN or 40 PREN, or any range of values therebetween. In some embodiments, the E_{pit}-E_{ocp} corrosion resistance of the steel alloy in a 3 wt% sodium chloride aqueous solution is, is about, is at least, or is at least about, 450 mV vs. SCE, 480 mV vs. SCE, 490 mV vs. SCE, 500 mV vs. SCE, 510 mV vs. SCE, 520 mV vs. SCE, 530 mV vs. SCE, 540 mV vs. SCE, 550 mV vs. SCE, 560 mV vs. SCE, 570 mV vs. SCE, 580 mV vs. SCE, 590 mV vs. SCE, 600 mV vs. SCE, 620 mV vs. SCE, 650 mV vs. SCE, 700 mV vs. SCE, 750 mV vs. SCE, 800 mV vs. SCE or 850 mV vs. SCE, or any range of values therebetween. In some embodiments, the corrosion current density of the steel alloy in a 3 wt% sodium chloride aqueous solution is, is about, is at least, or is at least about, 10 nA/cm^2, 15 nA/cm^2, 20 nA/cm^2, 25 nA/cm^2, 30 nA/cm^2, 35 nA/cm^2, 40 nA/cm^2, 45 nA/cm^2, 50 nA/cm^2, 55 nA/cm^2, 60 nA/cm^2, 65 nA/cm^2 or 70 nA/cm^2, or any range of values therebetween.

Alloy Yield Strength

[0063] The steel alloys may have improved yield strengths, which may improve dent resistance and scratch resistance.

[0064] In some embodiments, the yield strength of the steel alloy is, is at least, or is at least about, 900 MPa, 1000 MPa, 1050 MPa, 1100 MPa, 1150 MPa, 1200 MPa, 1250 MPa, 1300 MPa, 1450 MPa, 1500 MPa, 1600 MPa, 1700 MPa, 1800 MPa, 2000 MPa or 2500 MPa, or any range of values therebetween.

Alloy Ultimate Tensile Strength

[0065] In some embodiments, the ultimate tensile strength of the steel alloy is, is about, is at least, or is at least about, 800 MPa, 900 MPa, 1000 MPa, 1050 MPa, 1100 MPa, 1150 MPa, 1200 MPa, 1250 MPa, 1300 MPa, 1450 MPa, 1500 MPa, 1600 MPa, 1700 MPa, 1800 MPa, 2000 MPa or 2500 MPa, or any range of values therebetween.

Alloy Ductility

[0066] The ductility of the steel alloy may also be considered such that the parts are suitable for use in automobile applications. Ductility of an alloy may be measured by the bend angle and/or the elongation of the alloy, although bend angle is preferred.

[0067] In some embodiments, bend angle of an alloy is, is about, is at least, is at least about, is at most, or is at most about, 40°, 50°, 55°, 60°, 65°, 70°, 75°, 80°, 85°, 90°, 95°, 100°, 110°, 120°, 130°, 140° or 160°, or any range of values therebetween. In some embodiments, the bend angle is measured at a section thickness of, of about, of at most, of at most about, of at least, or of at least about, 1.0 mm, 1.5 mm, 1.8 mm, 2 mm, 2.2 mm, 2.5 mm, 2.8 mm, 3 mm, or 4 mm, or any range of values therebetween. In some embodiments, the bend angle is measured using the VDA238-100 evaluation standards. In some embodiments, a longitudinal bend angle is measured. In some embodiments, a longitudinal bend angle is the bend angle measured in the direction parallel with respect to the rolling direction. In some embodiments, a transverse bend angle is measured in a direction perpendicular to the rolling direction.

Processing Methods

[0068] Embodiments of the present disclosure include a process for preparing a cold-worked steel alloy. The steel alloy is cold-worked in order to improve alloy characteristics, such as hardness, strength, and/or corrosion resistance. In some embodiments, cold-working improves additional alloy characteristics, such as crystalline properties, yield strength, ultimate tensile strength and/or ductility. In some embodiments, cold-working is configured to achieve or maintain ductility relative to the steel alloy prior to cold-working. In some embodiments, cold-working may be performed by cold-rolling the alloy.

[0069] In some embodiments, the process further includes casting an alloy of the elemental composition described herein. In some embodiments, the process further includes hot-working (e.g., hot-rolling and/or hot wire drawing), annealing and/or pickling the alloy. In some embodiments, the process further includes hot-working (e.g. hot-rolling and/or hot wire drawing), annealing and/or pickling the alloy prior to cold-working (e.g. cold-rolling and/or cold wire drawing) the alloy. In some embodiments, hot-working of the alloy is performed prior to annealing and/or pickling the alloy. In some embodiments, hot-working of the alloy is performed subsequent to annealing and/or pickling the alloy.

[0070] In some embodiments, the process further includes cutting and/or machining the steel alloy and/or cold-worked steel alloy. In some embodiments, the steel alloy a monolithic metal sheet. In some embodiments, the monolithic metal sheet may be manufactured by providing an initial monolithic metal sheet, cutting the initial monolithic metal sheet to form a cut monolithic metal sheet, and shaping the cut monolithic metal sheet to form the monolithic metal sheet. In some embodiments, the monolithic metal sheet is in the shape of a door panel. In some embodiments, the monolithic metal sheet is in the shape of an external portion of a frame. In some embodiments, cutting is performed by laser cutting.

[0071] In some embodiments, the alloy is cold-work to a thickness reduction, relative to a thickness prior to cold-working, (i.e. cold-work% = 100 * ([initial thickness] – [cold-worked thickness]) / [initial thickness]) of, of about, of at least, of at least about, of at most, or of at most about, 20%, 25%, 30%, 35%, 40%, 42%, 44%, 46%, 48%, 50%, 52%, 55%, 60%, 65%, 70%, 75% or 80%, or any range of values therebetween. In some embodiments, the alloy is cold-worked to a thickness of, of about, of at most, or of at most about, 0.01 mm, 0.05 mm, 0.1 mm, 0.3 mm, 0.5 mm, 1 mm, 2 mm, 3 mm, 4 mm, 5 mm, 6 mm, 8 mm, 10 mm. In some embodiments, the cold worked steel alloy is in a form selected from a sheet, plate, wire, bar, or combinations thereof. In some embodiments, processing the steel alloy is performed prior to cold-working the steel alloy the processed steel alloy.

Vehicle

[0072] Embodiments of the present disclosure include vehicles that comprise the disclosed steel alloy. In some embodiments, at least one exterior panel and/or body of the vehicle comprises the steel alloy. In some embodiments, the vehicle architecture is designed such that the exterior panels of the vehicle also contribute to the vehicle's structural performance, wherein such exterior paneling of a vehicle may be referred to as an "exoskeleton." In some embodiments, the exterior panel is or is formed from a monolithic metal sheet of the steel alloy. In some embodiments, the corrosion resistance of the monolithic metal sheet allows for the exterior panel of the vehicle to be utilized without application of an anticorrosion coating or corrosion protective agent (e.g. paint). In some embodiments, an exterior surface of the exterior panel does not comprise paint.

[0073] In some embodiments, the vehicle is an automotive vehicle. In some embodiments, the vehicle comprises an electric motor. In some embodiments, the automotive vehicle is a truck or a car (e.g. sedan). In some embodiments, the exterior panel is selected from the group consisting of a door panel, a roof panel, an underbody panel, a hood panel, a fender panel, a trunk panel, a liftgate panel, and combinations thereof. In some embodiments, the exterior panel is the door panel.

[0074] Methods of manufacturing a vehicle, such as an automotive vehicle, are also disclosed. In some embodiments, a monolithic metal sheet is provided, at least one component is attached directly to the monolithic metal sheet to form an exterior panel, and the exterior panel is attached to an exterior portion of a vehicle body.

EXAMPLES

Example 1 - 50lb Scale

[0075] An alloy within the target ranges of alloy A4 was prepared at a 50lb scale, with the actual compositional alloy elemental values shown in Table 3. The alloy was formed by casting the alloy, then machining the alloy, then hot rolling the alloy, and then annealing and pickling the alloy. The alloy was then tested and imaged after annealing and pickling of the alloy, and also tested and imaged after a subsequent cold rolling of the alloy to various degrees.

Table 3

Chemistry	Fe	C	N	Cr	Ni	Mn	Si	Mo	P	S
Target	Bal.	0.03 Max	0.15-0.25	16-18	5-6	1.5-2.5	0.75 Max	1.0-2.0	0.045 Max	0.03 Max
Actual	Bal.	0.028	0.18	16.9	5.5	1.9	0.3	1.5	0.004	0.002

[0076] The actual alloy composition of Table 3 was cold-worked to various degrees wherein Table 4 summarizes results for various cold work amounts. FIGS. 4A and 4B show optical micrographs of the actual alloy composition of Table 3 cold-worked to 24% reduction. FIGS. 5A and 5B show optical micrographs of the actual alloy composition of Table 3 cold-worked to 36% reduction. FIGS. 6A and 6B show optical micrographs of the actual alloy composition of Table 3 cold-worked to 44% reduction. FIGS. 7A and 7B show optical micrographs of the actual alloy composition of Table 3 cold-worked to 56% reduction. Table 4 summarizes the experimental data of the actual alloy composition of Table 4 cold-worked to different reduction percentages.

Table 4

Cold Work	Thickness	0.2% Offset Yield Strength	Ultimate Tensile Strength	Uniform Elongation	Total Elongation (2")	Hardness HRB/HRC	Feritscope % Ferrite Top	Feritscope % Ferrite Bottom
%	mm	Mpa	Mpa	%	%	HRB/HRC	%	%
0	4.9	350	791	43	49	88 HRB	Not measured	Not measured
19	4.0	694	1084	23	28	33 HRC	Not measured	Not measured
24	3.8	809	1158	20	24	37 HRC	7	12
36	3.2	1048	1268	16	20	43 HRC	14	18
44	2.8	1173	1331	13	17	45 HRC	20	24
53	2.3	1291	1389	2	14	45 HRC	Not measured	Not measured
56	2.2	1338	1458	2	8	46 HRC	25	30

Example 2 - 50kg Scale

[0077] Alloys within the target ranges of alloys A4, A7 and A8 were prepared at a 50kg scale, with the actual compositional alloy elemental values shown in Table 5. The alloys were formed by casting the alloy, then annealing and pickling the alloy, and then hot rolling the alloy. The alloys were then tested and imaged after annealing and pickling of the alloys, and also tested and imaged after a subsequent cold rolling of the alloys to various degrees.

Table 5

Chemistry	Fe	C	N	Cr	Ni	Mn	Si	Mo	P	S	Cu
A4 Target	Bal.	0.03 Max	0.15-0.25	16-18	5-6	1.5-2.5	0.75 Max	1.0-2.0	0.045 Max	0.03 Max	0.2-0.4
A4 Actual	Bal.	0.013	0.181	16.82	5.56	2.01	0.32	1.53	0.009	0.0047	0.3
A7 Target	Bal.	0.03 Max	0.05-0.15	15-17	6-8	1.5-2.5	0.75 Max	0.5-1.5	0.03 Max	0.03 Max	0.2-0.4
A7 Actual	Bal.	0.011	0.109	16.02	7.03	2.02	0.31	1.1	0.008	0.0044	0.3
A8 Target	Bal.	0.03 Max	0.05-0.15	15-17	4-6	4-6	0.75 Max	0.75-1.5	0.03Max	0.03 Max	0.2-0.4
A8 Actual	Bal.	0.009	0.104	15.87	5.03	5.02	0.31	1.24	0.008	0.0055	0.29

[0078] The actual alloy compositions of Table 5 for alloys A4, A7 and A8 were cold-worked to various degrees wherein Tables 6A-6C summarize results for various cold work amounts. The hardness, strength and elongation experimental properties are shown in

FIG. 8 for the actual alloy compositions of Table 5 for alloys A4, A7 and A8. FIGS. 9-11 shows the longitudinal stress-strain experimental data for the actual alloy compositions of Table 5 for alloys A4, A7 and A8, respectively, cold-worked to various degrees. FIGS. 12A, 12B and 12C show optical micrographs of the actual alloy composition of Table 5 for alloys A4, A7 and A8, respectively, that have been cold-worked.

Table 6A

	Cold Work	Thickness	Orientation	0.2% Offset Yield Strength	Ultimate Tensile Strength
Unit	%	mm		Mpa	Mpa
A4	0	5.14	L	383.0	790.0
A4	0	5.13	T	393.0	788.0
A4	40	3.04	L	820.7	1254.5
A4	40	3.03	T	1023.7	1323.7
A4	50	2.54	L	1160.9	1333.3
A4	50	2.56	T	1164.5	1428.6
A4	60	2.06	L	1352.2	1457.4
A4	60	2.08	T	1333.4	1564.7
A7	0	4.96	L	320.7	688.2
A7	0	4.96	T	348.0	702.5
A7	40	3.04	L	1007.7	1099.8
A7	40	3.03	T	917.8	1079.0
A7	50	2.53	L	979.1	1203.9
A7	50	2.54	T	1051.7	1203.0
A7	60	2.04	L	1222.8	1317.3
A7	60	2.05	T	1210.0	1386.9
A8	0	4.99	L	335.5	731.3
A8	0	4.99	T	365.8	744.2
A8	40	3.06	L	1049.5	1175.1
A8	40	3.06	T	1026.2	1233.7
A8	50	2.51	L	1163.7	1317.0
A8	50	2.51	T	1184.7	1354.0
A8	60	2.09	L	1256.3	1402.6
A8	60	2.11	T	1300.2	1460.4

Table 6B

	Cold Work	Thickness	Orientation	Uniform Elongation	Total Elongation (2")
Unit	%	mm		%	%
A4	0	5.14	L	38.4	45.0
A4	0	5.13	T	36.7	41.9
A4	40	3.04	L	15.3	19.8
A4	40	3.03	T	9.2	12.1
A4	50	2.54	L	0.8	16.3
A4	50	2.56	T	7.6	10.7
A4	60	2.06	L	0.7	8.1
A4	60	2.08	T	4.1	5.7
A7	0	4.96	L	40.4	47.5
A7	0	4.96	T	38.9	45.7
A7	40	3.04	L	12.2	17.3
A7	40	3.03	T	1.3	1.5
A7	50	2.53	L	1.0	11.8
A7	50	2.54	T	3.1	5.2
A7	60	2.04	L	0.7	6.7
A7	60	2.05	T	4.7	7.4
A8	0	4.99	L	41.5	48.1
A8	0	4.99	T	38.1	43.9
A8	40	3.06	L	1.3	12.0
A8	40	3.06	T	5.6	11.7
A8	50	2.51	L	0.9	6.3
A8	50	2.51	T	1.9	7.3
A8	60	2.09	L	0.8	5.0
A8	60	2.11	T	2.0	5.2

Table 6C

	Cold Work	Thickness	Orientation	Hardness	Feritscope % Ferrite Top	Feritscope % Ferrite Bottom
Unit	%	mm		HV	%	%
A4	0	5.14	L	207.5	0.9	1.1
A4	0	5.13	T			
A4	40	3.04	L	417.5	24.5	25.1
A4	40	3.03	T			
A4	50	2.54	L	453.0	28.6	27.9
A4	50	2.56	T			
A4	60	2.06	L	482.0	34.8	34.3
A4	60	2.08	T			
A7	0	4.96	L	188.0	0.9	0.6
A7	0	4.96	T			
A7	40	3.04	L	394.0	29.6	27.8
A7	40	3.03	T			
A7	50	2.53	L	410.0	34.3	32.7
A7	50	2.54	T			
A7	60	2.04	L	442.5	38.2	40.6
A7	60	2.05	T			
A8	0	4.99	L	189.5	1.5	1.8
A8	0	4.99	T			
A8	40	3.06	L	416.0	33.6	33.2
A8	40	3.06	T			
A8	50	2.51	L	434.0	39.2	39.5
A8	50	2.51	T			
A8	60	2.09	L	459.5	46.2	46.2
A8	60	2.11	T			

Example 3

[0079] An alloy within the target ranges of A4 alloy was prepared at a 170 metric ton scale and a 50 kg scale. An alloy within the target ranges of A7 alloy was prepared at a 50 kg scale. The alloy was formed by casting the alloy, then machining the alloy, then hot rolling the alloy, and then annealing and pickling the alloy. The alloy was then tested after annealing and pickling of the alloy (labeled as Annealed), and also tested after a subsequent cold rolling of the alloy (labeled as Cold rolled).

[0080] FIG. 13A shows the experimental results of E_{pit}-E_{ocp} corrosion resistance of A4 alloy and A7 alloy prepared at a 50kg scale (lab scale) and 170 metric ton scale (mill scale) in a 3 wt% sodium chloride aqueous solution measured against a standard calomel electrode (SCE). As shown in the FIG. 13A, A4 alloy has a E_{pit}-E_{ocp} corrosion resistance of approaching or more than 700 mV prepared at a 170 metric ton scale. FIG. 13B shows the experimental results of corrosion current density I_{corr} of A4 alloy and A7 alloy prepared at a 50kg scale (lab scale) and 170 metric ton scale (mill scale) in a 3 wt% sodium chloride aqueous solution.

[0081] Table 7 summarizes some of the experimental results of corrosion resistance for A4 and A7 alloys in different conditions.

Table 7

Alloy	Alloy ID	Condition	E_{pit}-E_{ocp} (mV v. SCE)	I_{corr} (nA/cm^2)
A4	Alloy 1	Mill scale, annealed	775 ± 43	29 ± 5
A4	Alloy 1	Mill scale, cold-worked	696 ± 37	21 ± 11
A7	Alloy 2	Lab scale, annealed	391 ± 18	32 ± 10
A7	Alloy 2	Lab scale, cold-worked	435 ±5	42 ± 19

Example 4

[0082] An alloy within the target ranges of A4, A7, B1, B2 and B3 alloys were prepared at a 50 kg scale (lab scale). An alloy within the target ranges of A4 alloy was also prepared at a 170 metric ton scale. The alloy was formed by casting the alloy, then machining the alloy, then hot rolling the alloy, and then annealing and pickling the alloy. The alloy was then tested after annealing and pickling of the alloy (labeled as Annealed).

[0083] FIG. 14A shows the experimental results of E_{pit}-E_{ocp} corrosion resistance of A4, A7, B1, B2, and B3 alloys prepared at a 50kg scale (lab scale) and A4 alloy prepared at a 170 metric ton scale (mill scale) in a 3 wt% sodium chloride aqueous solution measured against a standard calomel electrode (SCE). FIG. 14B shows the experimental results of corrosion current density I_{corr} of A4, A7, B1, B2, and B3 alloys prepared at a 50kg scale (lab scale) and A4 alloy (mill scale) prepared at a 170 metric ton scale in a 3 wt% sodium chloride aqueous solution.

[0084] FIG. 15A shows the experimental results of E_{pit}-E_{ocp} corrosion resistance of A4, A7, B1, B2, and B3 alloys prepared at a 50kg scale (lab scale) and A4 alloy prepared at a 170 metric ton scale (mill scale) in a 3 wt% sodium chloride aqueous solution measured against a standard calomel electrode (SCE) versus corrosion resistance in pitting resistance equivalent number (PREN). FIG. 15B shows the experimental results of corrosion current density I_{corr} of A4, A7, B1, B2, and B3 alloys prepared at a 50kg scale (lab scale) and A4 alloy prepared at a 170 metric ton scale (mill scale) in a 3 wt% sodium chloride aqueous solution measured against a standard calomel electrode (SCE) versus corrosion resistance in pitting resistance equivalent number (PREN).

Example 5

[0085] An alloy within the target ranges of Alloy 1 (i.e., A4 alloy), Alloy 2 (i.e., A7 alloy), and Alloy 4 (i.e., B1 alloy) were prepared at a 50 kg scale. The alloy was formed by casting the alloy, then machining the alloy, then hot rolling the alloy, and then annealing and pickling the alloy. The alloy was then tested after annealing and pickling of the alloy (labeled as Annealed), and also tested after a subsequent cold rolling of the alloy (labeled as Cold rolled).

[0086] FIG. 16A shows the experimental results of E_{pit}-E_{ocp} corrosion resistance of Alloy 1 (i.e., A4 alloy), Alloy 2 (i.e., A7 alloy), and Alloy 4 (i.e., B1 alloy) prepared in a 50kg scale annealed and cold-worked in a 3 wt% sodium chloride aqueous solution measured against a standard calomel electrode (SCE). FIG. 16B shows the experimental results of corrosion current density I_{corr} of Alloy 1, Alloy 2, and Alloy 4 prepared in a 50kg scale annealed and cold-worked in a 3 wt% sodium chloride aqueous solution.

[0087] Table 8 summarizes some of the experimental results of corrosion resistance for Alloy 2 and Alloy 4 in different conditions.

Table 8

Alloy	Alloy ID	Condition	E_{pit}-E_{ocp} (mV v. SCE)	I_{corr} (nA/cm^2)
A7	Alloy 2	Lab scale, annealed	391 ± 18	32 ± 10
A7	Alloy 2	Lab scale, cold-worked	435 ±5	42 ± 19
B1	Alloy 4	Lab scale, annealed	378 ± 16	25 ± 8
B1	Alloy 4	Lab scale, cold-worked	406 ± 16	14 ± 3

Example 6

[0088] An alloy within the target range of Alloy 1 (i.e., A4 alloy) was prepared. FIG. 17 shows the longitudinal and transverse bend angles of Alloy 1 according to some examples in comparison to Type 301 stainless steel. As shown in FIG. 17, the longitudinal bend angle of Alloy 1 is about 84°, the transverse bend angle of Alloy 1 is about 122°, while the longitudinal bend angle for Type 301 alloy is about 64°, and the transverse bend angle for Type 301 alloy is about 109°. Both the longitudinal bend angle and the transverse bend angle of Alloy 1 are larger than the Type 301 alloy, which shows that the Alloy 1 is more ductile than Type 301 alloy.

Example 7

[0089] An alloy within the target range of A4 alloy was prepared at a 170 metric ton scale. The alloy was formed by casting the alloy, then machining the alloy, then hot rolling the alloy, and then annealing and pickling the alloy. The alloy was then annealed and pickled, and was tested after a subsequent cold rolling of the alloy.

[0090] FIG. 18 shows the stress-strain experimental results for A4 alloy prepared in a 170 metric ton scale cold-worked in longitudinal direction, transverse direction, and 45° from the longitudinal direction. The stress-strain curve in a longitudinal direction is measured when a stress is applied in a direction parallel to the rolling direction of the alloy. The stress-strain curve in a transverse direction is measured when a stress is applied in a direction perpendicular to the rolling direction of the alloy.

[0091] While certain embodiments have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the disclosure. Indeed, the novel methods and systems described herein may be embodied in a variety of other forms. Furthermore, various omissions, substitutions and changes in the systems and methods described herein may be made without departing from the spirit of the disclosure. The accompanying claims and their equivalents are intended to cover such forms or modifications as would fall within the scope and spirit of the disclosure.

[0092] Features, materials, characteristics, or groups described in conjunction with a particular aspect, embodiment, or example are to be understood to be applicable to any other aspect, embodiment or example described in this section or elsewhere in this specification unless incompatible therewith. All of the features disclosed in this specification (including any accompanying claims, abstract and drawings), and/or all of the steps of any method or process so disclosed, may be combined in any combination, except combinations where at least some of such features and/or steps are mutually exclusive. The protection is not restricted to the details of any foregoing embodiments. The protection extends to any novel one, or any novel combination, of the features disclosed in this specification (including any accompanying claims, abstract and drawings), or to any novel one, or any novel combination, of the steps of any method or process so disclosed.

[0093] Furthermore, certain features that are described in this disclosure in the context of separate implementations can also be implemented in combination in a single implementation. Conversely, various features that are described in the context of a single implementation can also be implemented in multiple implementations separately or in any suitable subcombination. Moreover, although features may be described above as acting in certain combinations, one or more features from a claimed combination can, in some cases, be excised from the combination, and the combination may be claimed as a subcombination or variation of a subcombination.

[0094] Moreover, while operations may be depicted in the drawings or described in the specification in a particular order, such operations need not be performed in the particular order shown or in sequential order, or that all operations be performed, to achieve desirable results. Other operations that are not depicted or described can be incorporated in the example methods and processes. For example, one or more additional operations can be performed before, after, simultaneously, or between any of the described operations. Further, the operations may be rearranged or reordered in other implementations. Those skilled in the art will appreciate that in some embodiments, the actual steps taken in the processes illustrated and/or disclosed may differ from those shown in the figures. Depending on the embodiment, certain of the steps described above may be removed, others may be added. Furthermore, the features and attributes of the specific embodiments disclosed above may be combined in different ways to form additional embodiments, all of which fall within the scope of the present disclosure. Also, the separation of various system components in the implementations described above should not be understood as requiring such separation in all implementations, and it should be understood that the described components and systems can generally be integrated together in a single product or packaged into multiple products. For example, any of the components for an energy storage system described herein can be provided separately, or integrated together (e.g., packaged together, or attached together) to form an energy storage system.

[0095] For purposes of this disclosure, certain aspects, advantages, and novel features are described herein. Not necessarily all such advantages may be achieved in accordance with any particular embodiment. Thus, for example, those skilled in the art will recognize that the disclosure may be embodied or carried out in a manner that achieves one advantage or a group of advantages as taught herein without necessarily achieving other advantages as may be taught or suggested herein.

[0096] Conditional language, such as "can," "could," "might," or "may," unless specifically stated otherwise, or otherwise understood within the context as used, is generally intended to convey that certain embodiments include, while other embodiments do not include, certain features, elements, and/or steps. Thus, such conditional language is not generally intended to imply that features, elements, and/or steps are in any way required for one or more embodiments or that one or more embodiments necessarily include logic for deciding, with or without user input or prompting, whether these features, elements, and/or steps are included or are to be performed in any particular embodiment.

[0097] Conjunctive language such as the phrase "at least one of X, Y, and Z," unless specifically stated otherwise, is otherwise understood with the context as used in general to convey that an item, term, etc. may be either X, Y, or Z. Thus, such conjunctive language is not generally intended to imply that certain embodiments require the presence of at least one of X, at least one of Y, and at least one of Z.

[0098] Language of degree used herein, such as the terms "approximately," "about," "generally," and "substantially" as used herein represent a value, amount, or characteristic close to the stated value, amount, or characteristic that still performs a desired function or achieves a desired result. For example, the terms "approximately," "about," "generally," and "substantially" may refer to an amount that is within less than 10% of, within less than 5% of, within less than 1% of, within less than 0.1% of, and within less than 0.01% of the stated amount, depending on the desired function or desired result.

[0099] The scope of the present disclosure is not intended to be limited by the specific disclosures of preferred embodiments in this section or elsewhere in this specification, and may be defined by claims as presented in this section or elsewhere in this specification or as presented in the future. The language of the claims is to be interpreted broadly based on the language employed in the claims and not limited to the examples described in the present specification or during the prosecution of the application, which examples are to be construed as non-exclusive.

[0100] The headings provided herein, if any, are for convenience only and do not necessarily affect the scope or meaning of the devices and methods disclosed herein.

WHAT IS CLAIMED IS:

1. A steel alloy composition, comprising:

Fe;

a hardness is at least about 400 HV; and

an E_{pit}-E_{ocp} corrosion resistance of at least about 500 mV in a 3 wt% sodium chloride aqueous solution.

2. The composition of Claim 1, wherein the hardness is about 420 HV to about 500 HV.

3. The composition of Claim 1 or Claim 2, wherein the E_{pit}-E_{ocp} corrosion resistance is about 520 mV to about 800 mV.

4. The composition of any one of Claims 1 to 3, further comprising a yield strength of at least about 1100 MPa.

5. The composition of any one of Claims 1 to 4, further comprising a ductility of at least about 60° bend angle at 1.6 mm thickness.

6. The composition of any one of Claims 1 to 5, wherein martensite formation begins at about 260 K to about 340 K.

7. The composition of any one of Claims 1 to 6, further comprising at least about 12 vol% martensite.

8. The composition of any one of Claims 1 to 7, further comprising a yield strength of at least about 1200 MPa.

9. The composition of any one of Claims 1 to 8, further comprising:

Cr: 15-18 wt.%;

Ni: 4-8 wt.%;

Mn: 1.5-6 wt.%; and

Fe: Bal.

10. The composition of Claims 9, further comprising:

N: at most about 0.25 wt.%.

11. The composition of Claim 9 or Claim 10, further comprising:

Mo: at most about 2 wt.%.

12. The composition of any one of Claims 9 to 11, further comprising:

C: at most about 0.03 wt.%;

Si: at most about 0.75 wt.%;

P: at most about 0.045 wt.%; and

S: at most about 0.03 wt.%.

13. The composition of any one of Claims 9 to 12, further comprising:

Cu: at most about 0.5 wt.%;

Co: at most about 0.8 wt.%;

Al: at most about 0.03 wt.%;

Ti: at most about 0.03 wt.%; and

B: at most about 0.05 wt.%.

14. The composition of Claim 13, further comprising at most about 0.05 wt.% of each of at least one additional element, and a total of at most about 0.15 wt.% of the at least one additional element.

15. A process for preparing an alloy, comprising:

casting a steel alloy comprising Fe;

performing a processing step on the steel alloy selected from the group consisting of hot-working, annealing, pickling and combinations thereof to form a processed steel alloy; and

cold working the processed steel alloy to form a cold worked steel alloy with a hardness is at least about 400 HV and an E_{pit}-E_{ocp} corrosion resistance of at least about 500 mV in a 3 wt% sodium chloride aqueous solution.

16. The process of Claim 15, wherein the processed steel alloy is cold-worked to a thickness reduction of at least about 30%.

17. The process of Claim 15 or Claim 16, wherein the cold worked steel has a thickness of about 0.01 mm to about 4 mm.

18. The process of any one of Claims 15 to 17, further comprises machining the cold worked steel.

19. The process of any one of Claims 15 to 18, wherein hot-working is performed prior to annealing the steel alloy.

20. The process of any one of Claims 15 to 19, wherein annealing is performed prior to hot-working the steel alloy.

21. The process of any one of Claims 15 to 20, wherein processing the steel alloy is performed prior to cold-working the steel alloy the processed steel alloy.

22. A vehicle comprising a vehicle body comprising the composition of claim 1.

23. The vehicle of Claim 22, wherein the vehicle body comprises an exterior vehicle body, and the exterior vehicle body comprises the steel alloy.

24. The vehicle of Claim 22 or Claim 23, wherein the steel alloy is uncoated.

25. The vehicle of any one of Claims 22 to 24, wherein a corrosion protective agent is not disposed over the steel alloy.

26. The vehicle of Claim 25, wherein the corrosion protective agent is paint.

27. The vehicle of any one of Claims 22 to 26, wherein the vehicle is an electric vehicle comprising an electric motor.

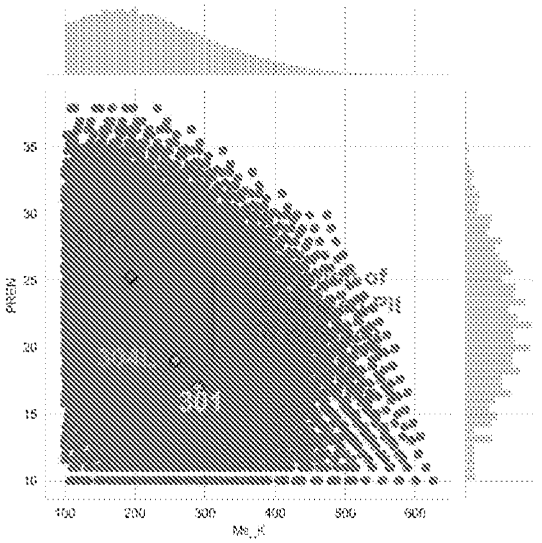

35
30
25
20
15
10
PREN
100
200
300
400
500
600
Ms_K
301

FIG. 1A

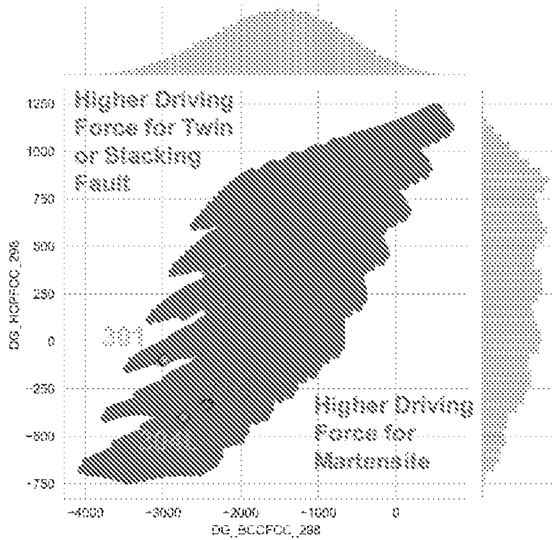

Higher Driving Force for Twin or Stacking Fault
Higher Driving Force for Martensite
301
1250
1000
750
500
250
0
-250
-500
-750
DG_HCPFCC_298
-4000
-3000
-2000
-1000
0
DG_BCCFCC_298

FIG. 1B

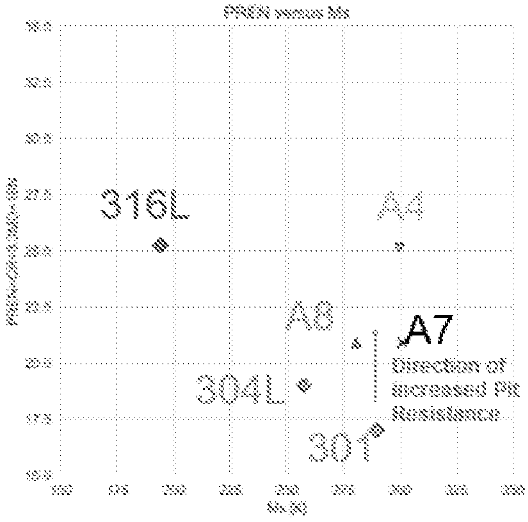


FIG. 2A

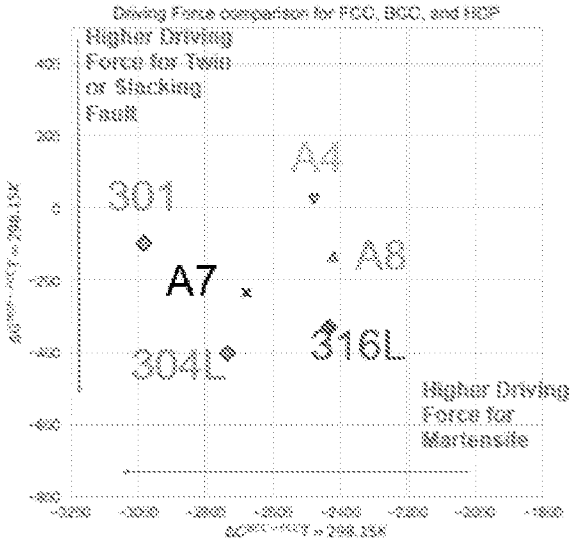


FIG. 2B

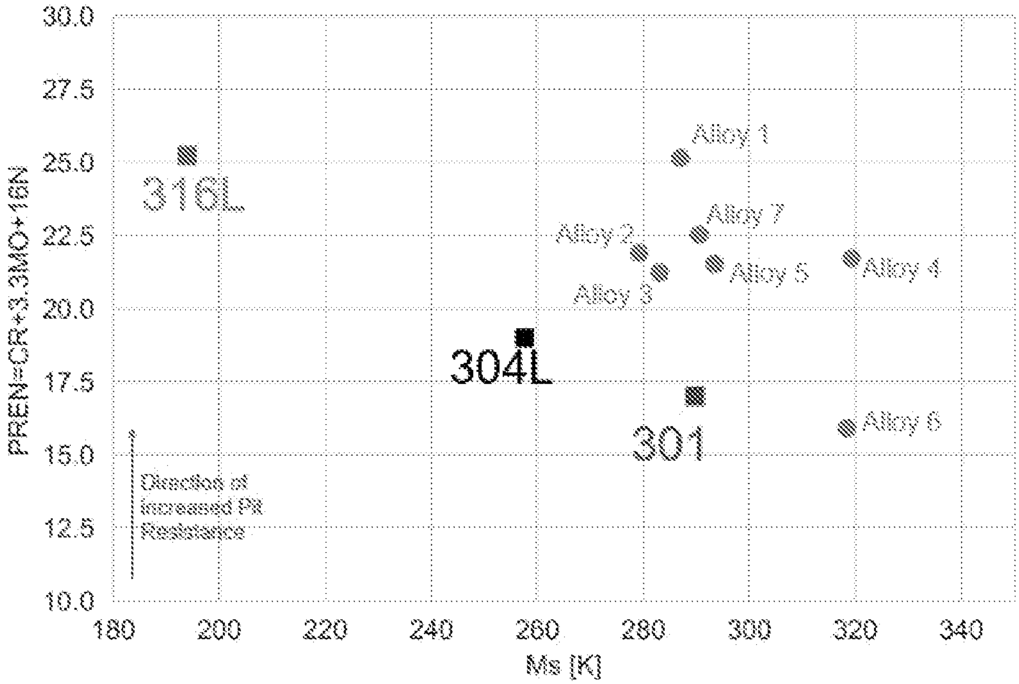
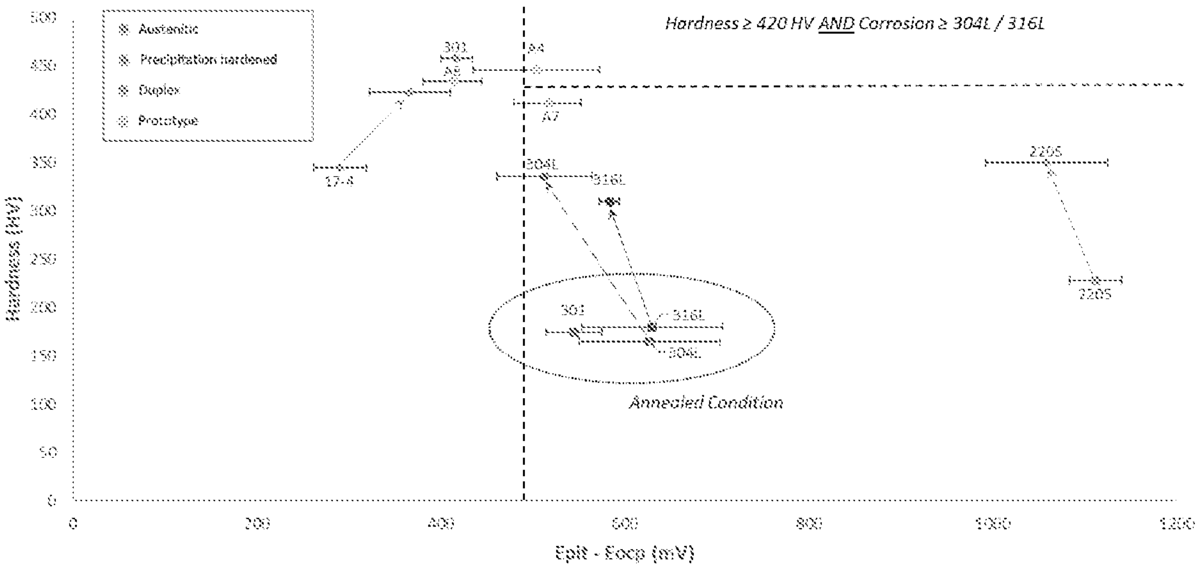


FIG. 2C



Austenitic
Precipitation hardened
Duplex
Prototype
Hardness ≥ 420 HV AND Corrosion ≥ 304L / 316L
301
A4
A7
17-4
304L
316L
2205
2205
301
316L
304L
Annealed Condition
Hardness (HV)
0
50
100
150
200
250
300
350
400
450
500
0
200
400
600
800
1000
1200
Epit - Eocp (mV)

FIG. 3

24% Cold Reduction

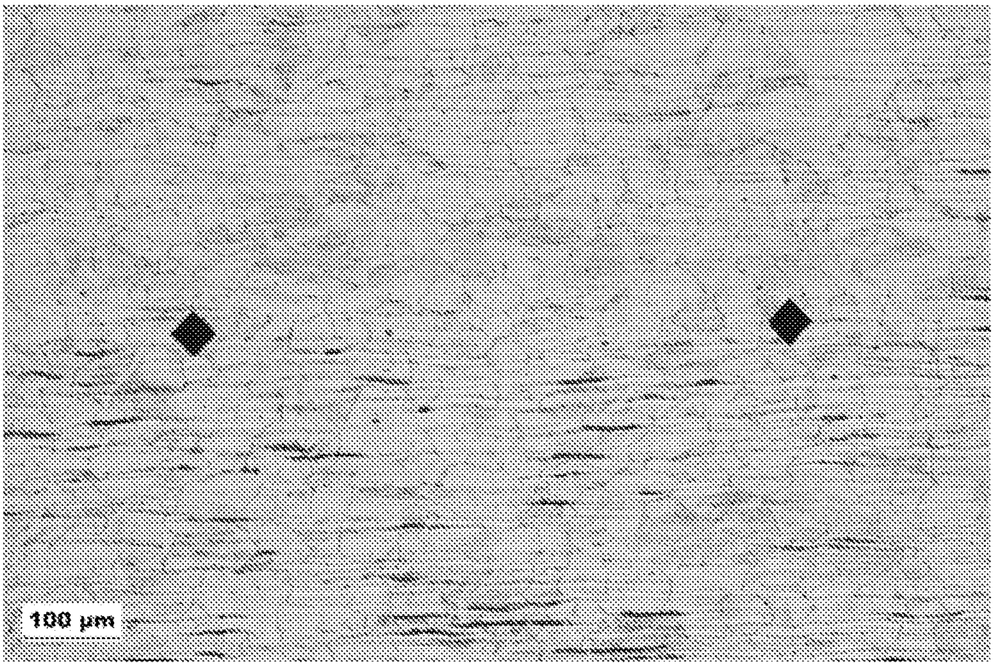


FIG. 4A

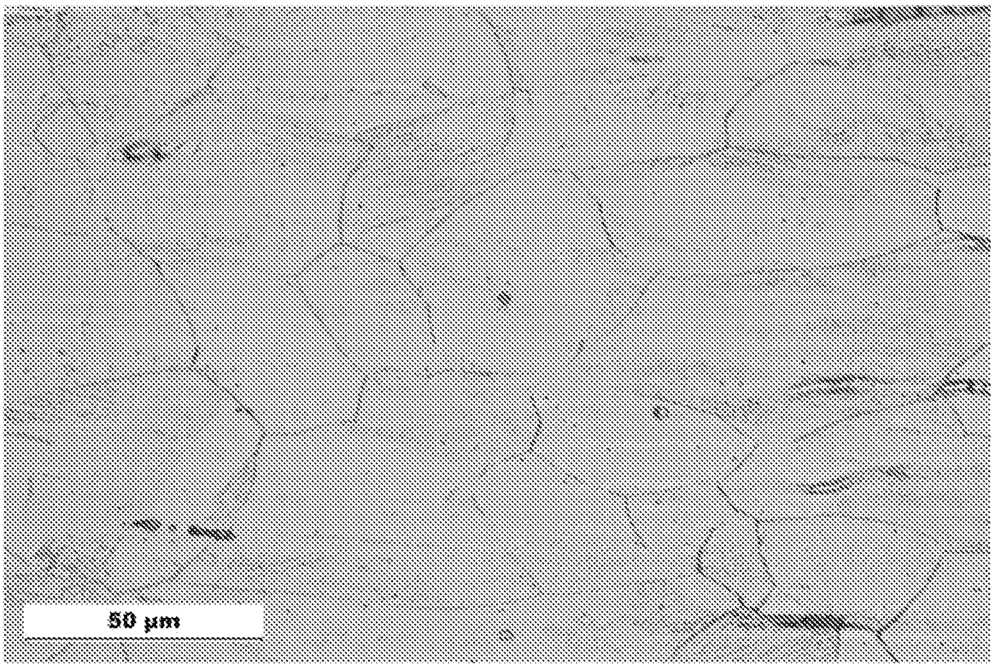


FIG. 4B

36% Cold Reduction

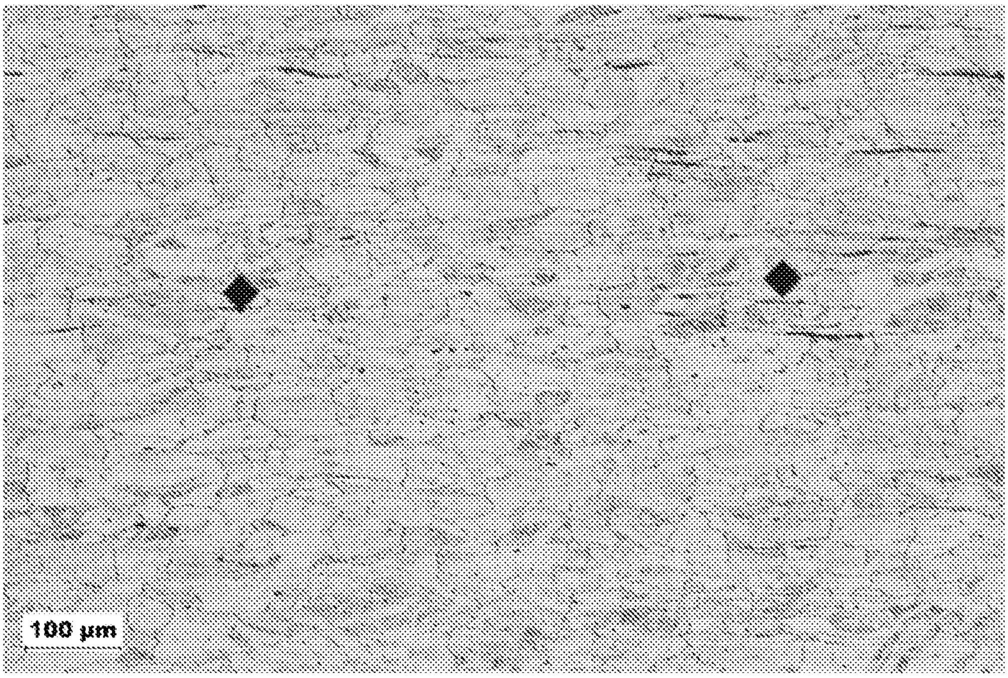


FIG. 5A

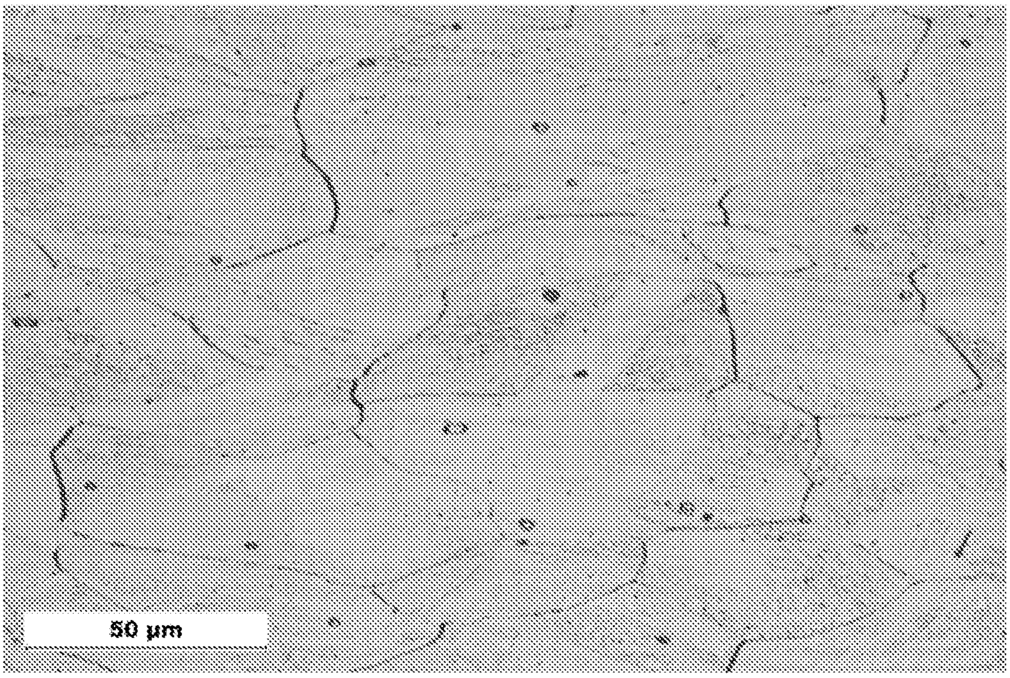


FIG. 5B

44% Cold Reduction

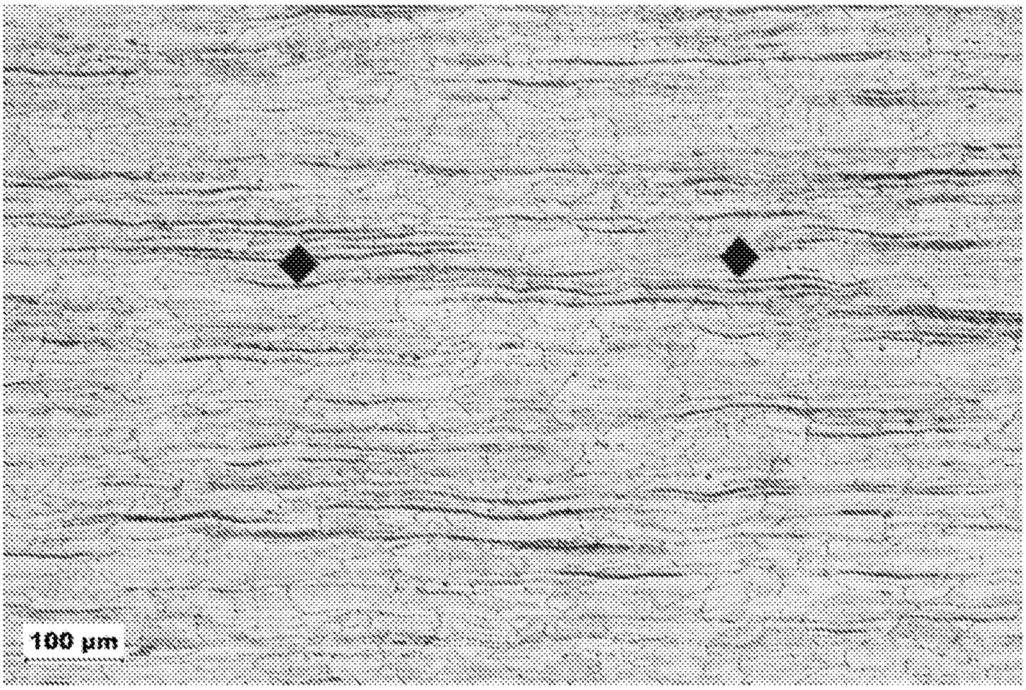


FIG. 6A

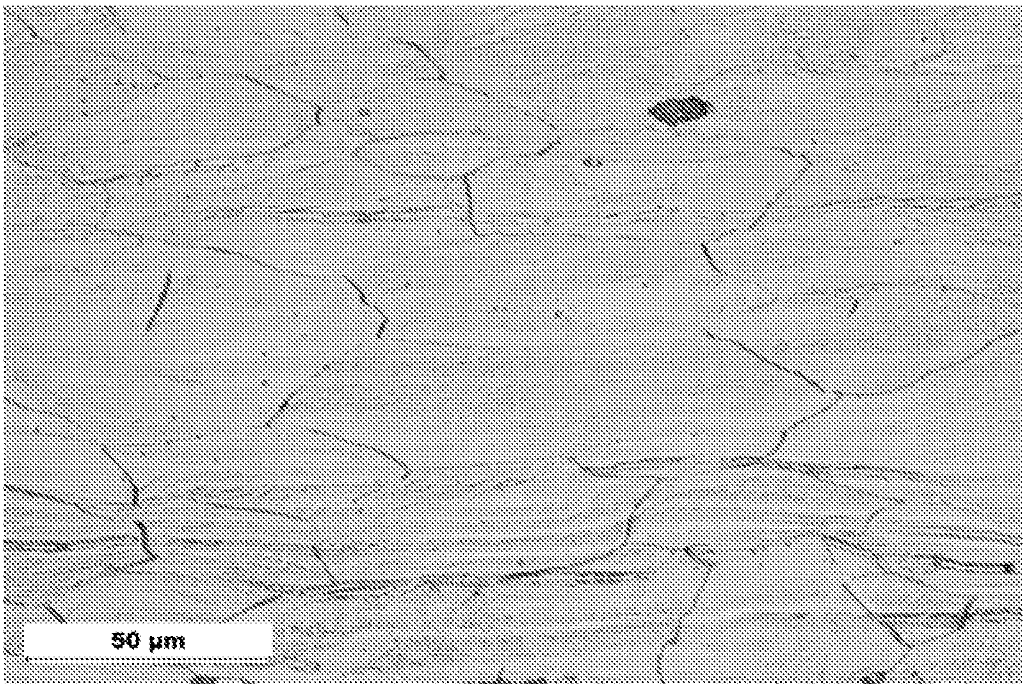


FIG. 6B

56% Cold Reduction

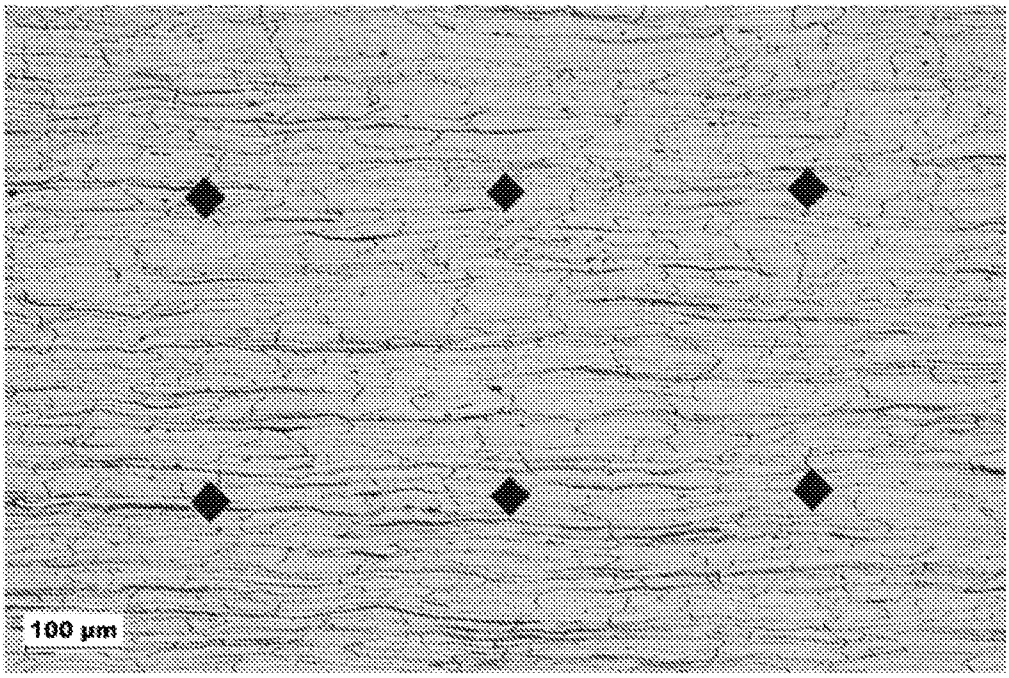


FIG. 7A

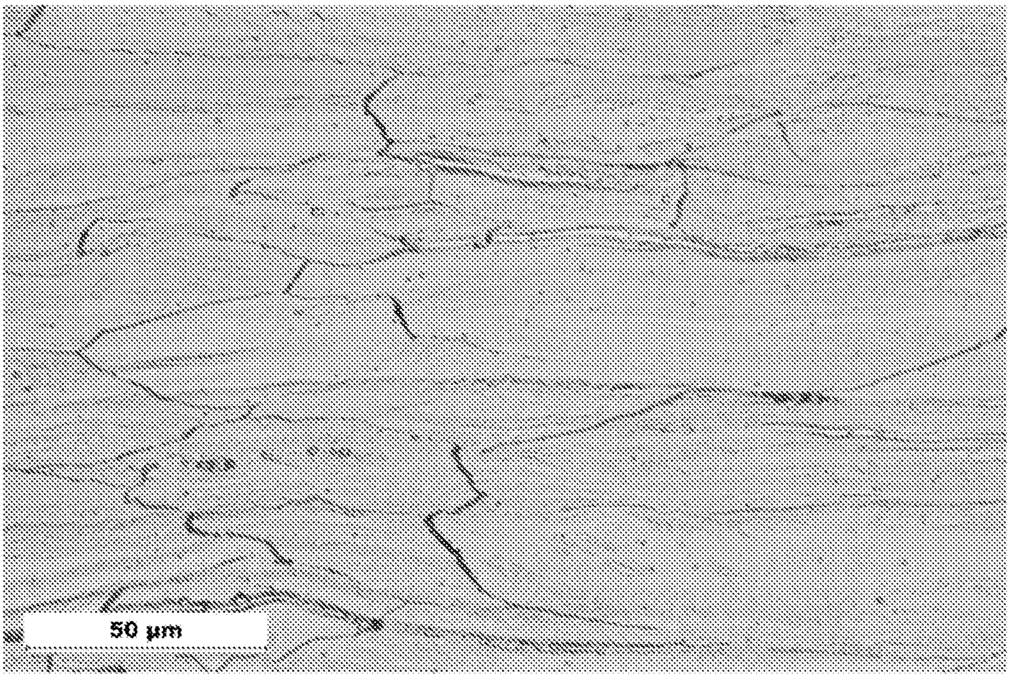


FIG. 7B

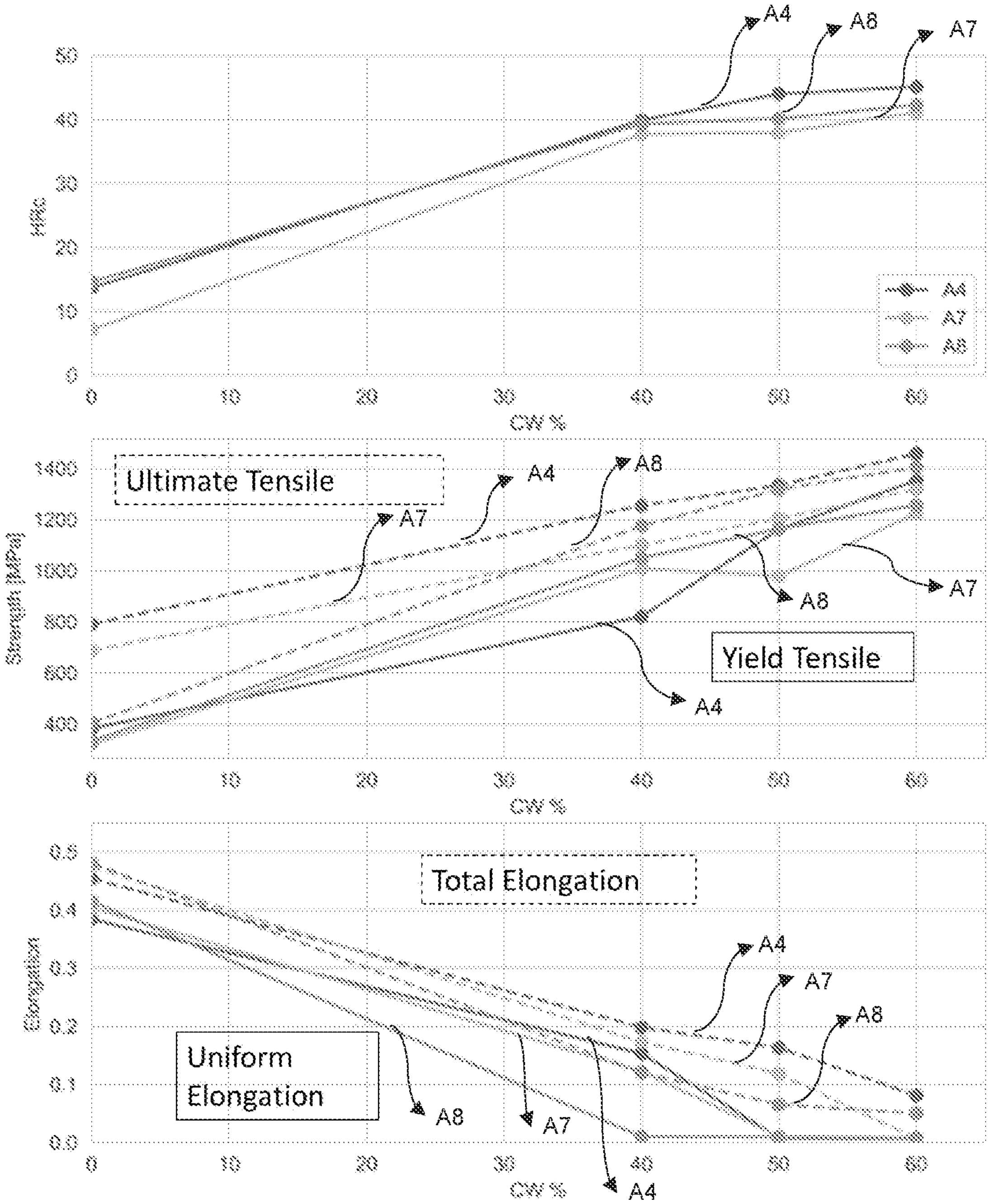

A4
A8
A7
50
40
30
20
10
0
HRc
0
10
20
30
40
50
60
CW %
A4
A7
A8
Ultimate Tensile
A4
A8
A7
1400
1200
1000
800
600
400
Strength [MPa]
A8
A7
Yield Tensile
A4
CW %
Total Elongation
0.5
0.4
0.3
0.2
0.1
0.0
Elongation
A4
A7
A8
Uniform
Elongation
A8
A7
A4
CW %

FIG. 8

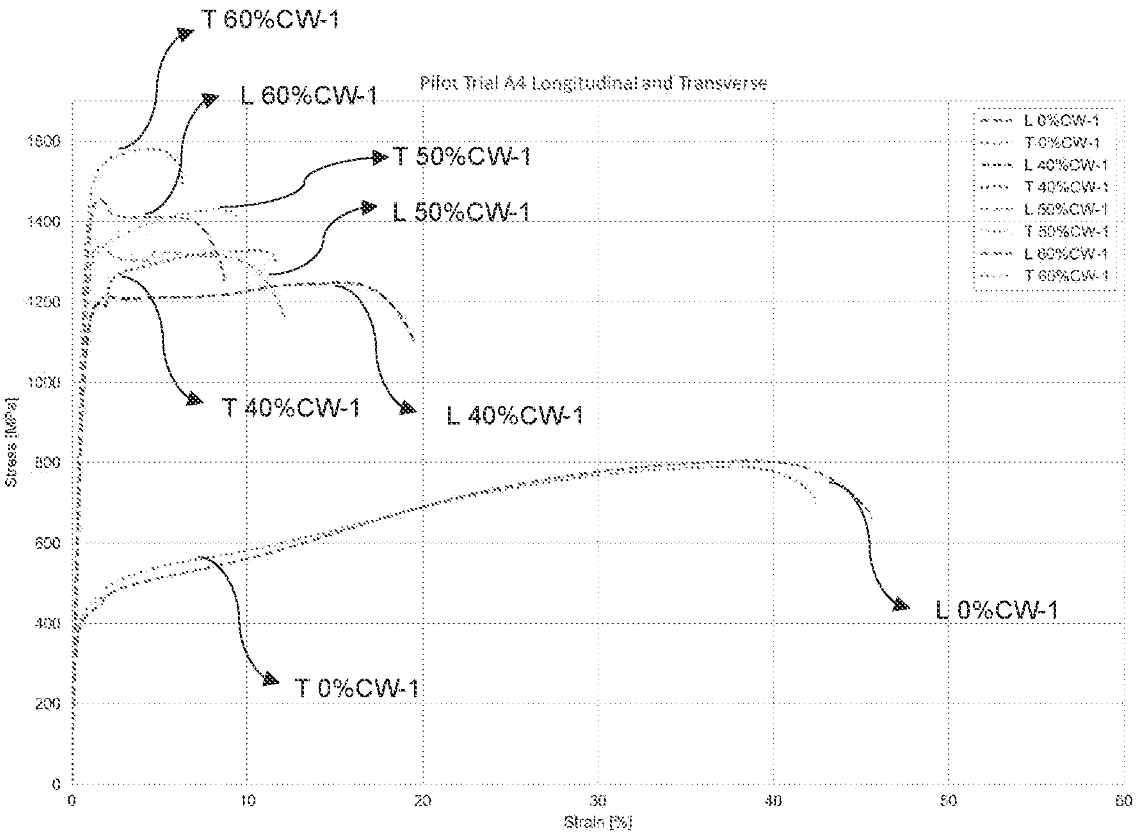

T 60%CW-1
L 60%CW-1
T 50%CW-1
L 50%CW-1
T 40%CW-1
L 40%CW-1
L 0%CW-1
T 0%CW-1
Pilot Trial A4 Longitudinal and Transverse
L 0%CW-1
T 0%CW-1
L 40%CW-1
T 40%CW-1
L 50%CW-1
T 50%CW-1
L 60%CW-1
T 60%CW-1
Stress [MPa]
Strain [%]
0
200
400
600
800
1000
1200
1400
1600
0
10
20
30
40
50
60

FIG. 9

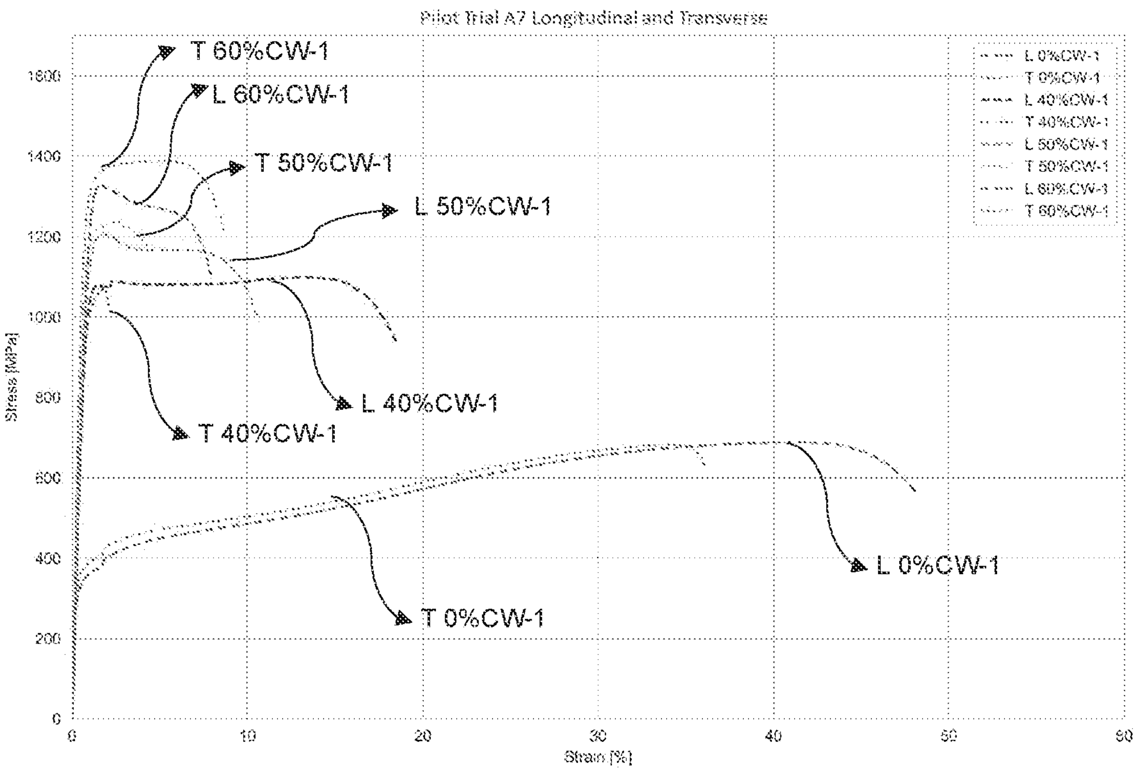
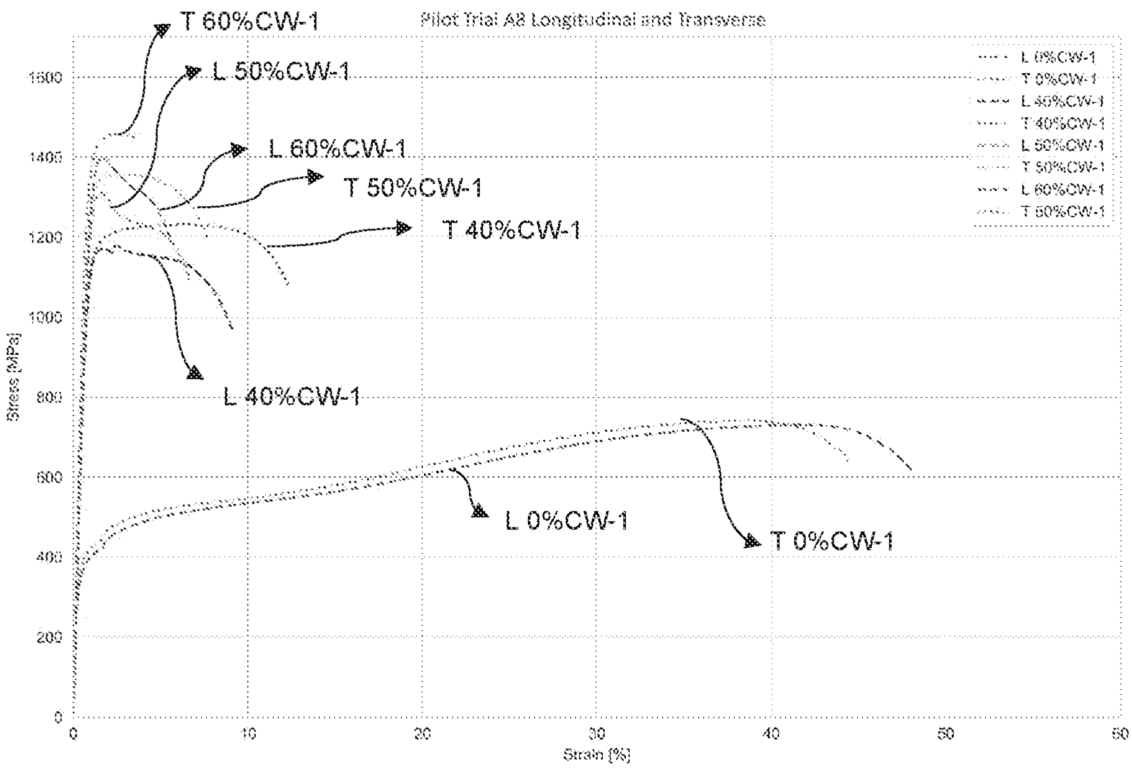

Pilot Trial A7 Longitudinal and Transverse
T 60%CW-1
L 60%CW-1
T 50%CW-1
L 50%CW-1
L 40%CW-1
T 40%CW-1
L 0%CW-1
T 0%CW-1
Stress [MPa]
Strain [%]
0
200
400
600
800
1000
1200
1400
1600
0
10
20
30
40
50
60

FIG. 10



Pilot Trial A8 Longitudinal and Transverse
T 60%CW-1
L 50%CW-1
L 60%CW-1
T 50%CW-1
T 40%CW-1
L 40%CW-1
L 0%CW-1
T 0%CW-1
L 0%CW-1
T 0%CW-1
L 40%CW-1
T 40%CW-1
L 50%CW-1
T 50%CW-1
L 60%CW-1
T 60%CW-1
Stress [MPa]
Strain [%]
0
200
400
600
800
1000
1200
1400
1600
0
10
20
30
40
50
60

FIG. 11

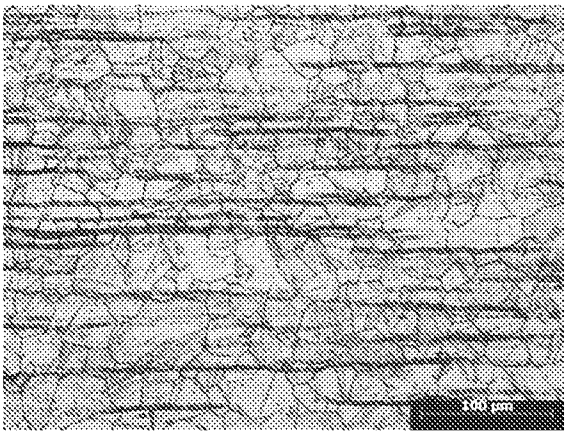


FIG. 12A

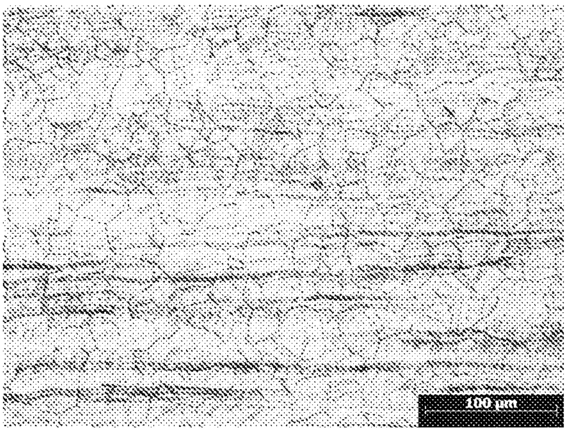


FIG. 12B

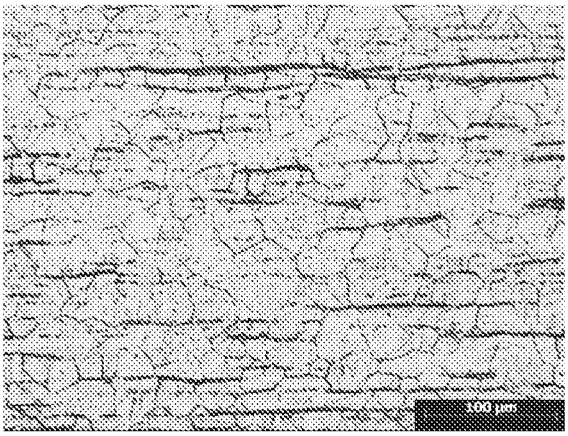


FIG. 12C

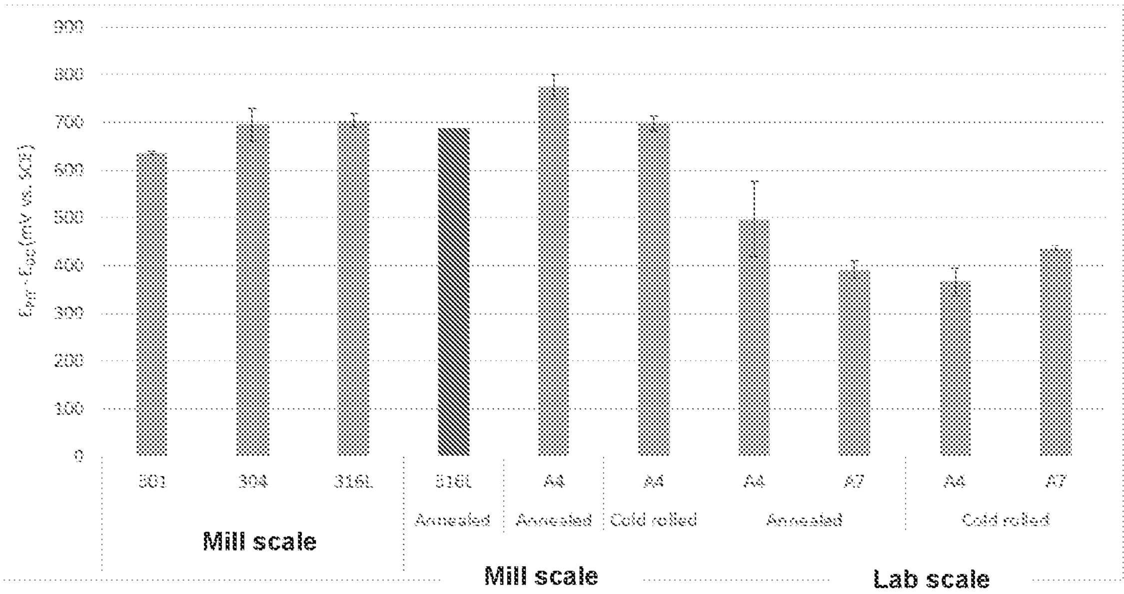


FIG. 13A

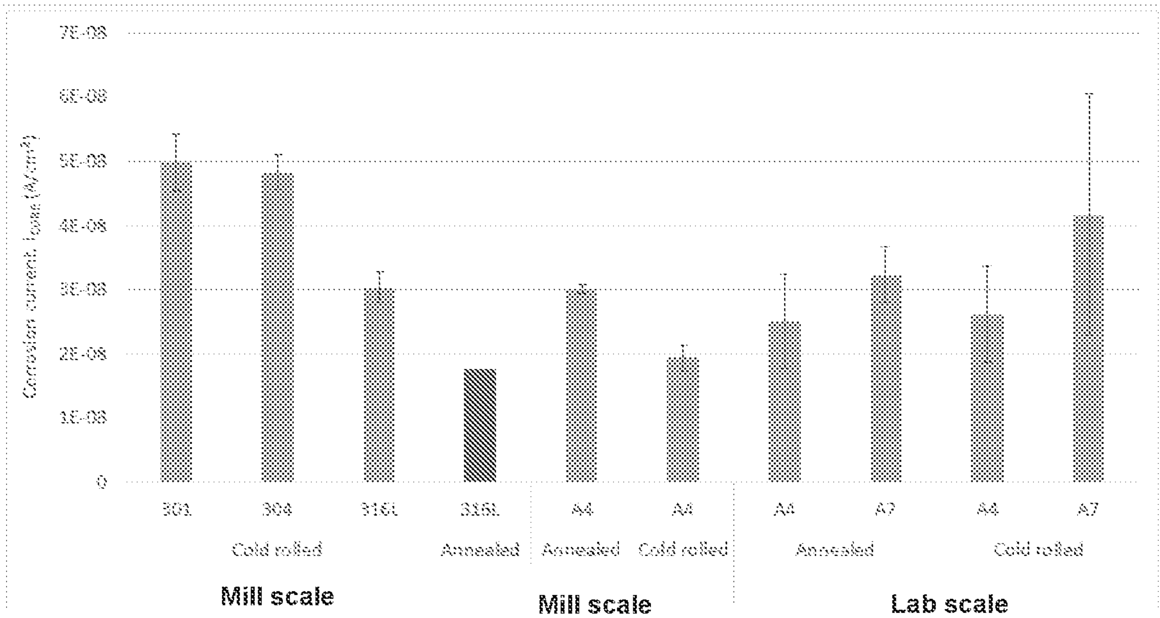


FIG. 13B

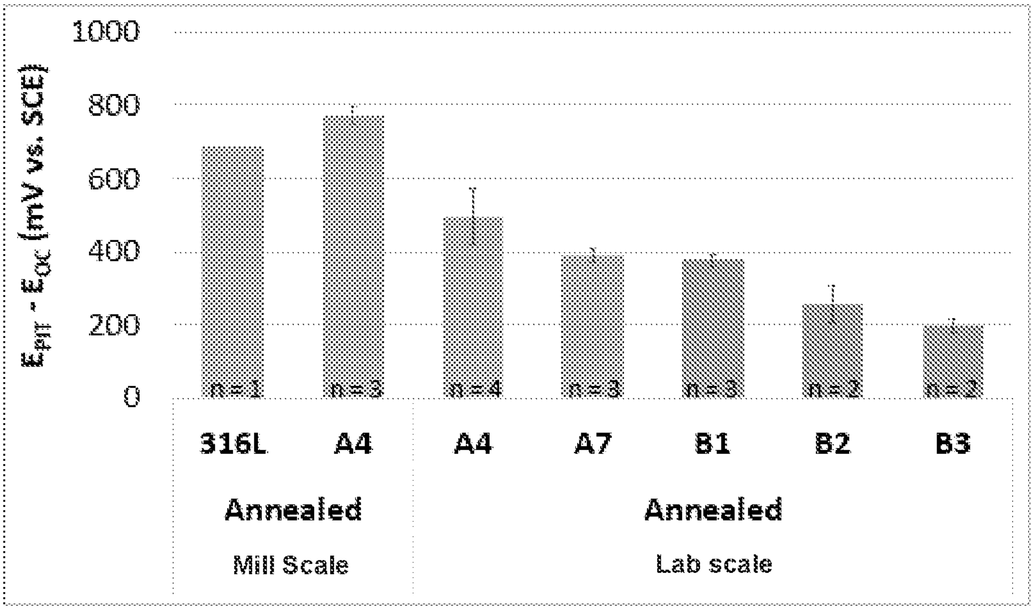


FIG. 14A

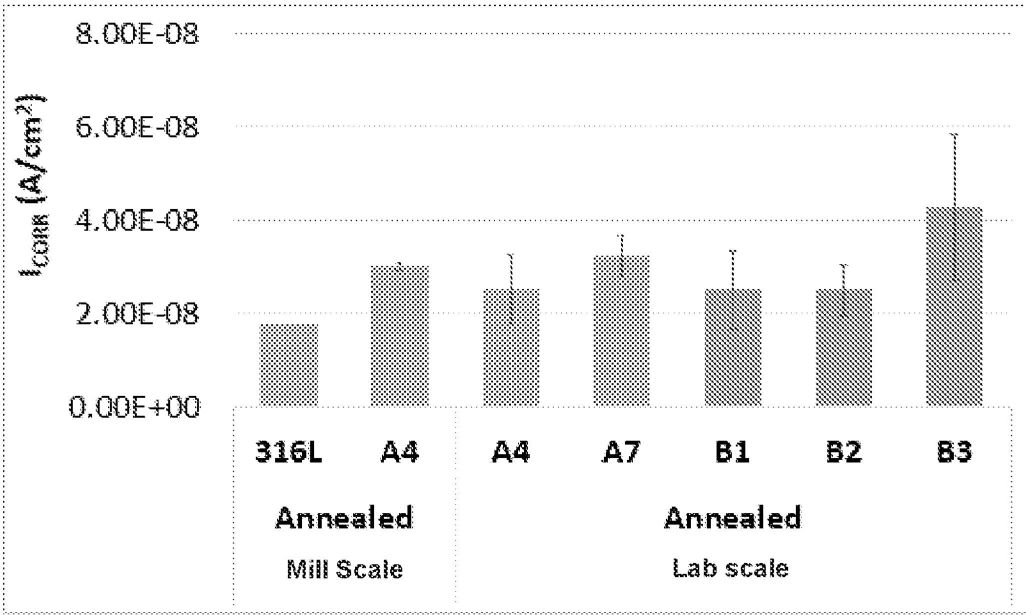


FIG. 14B

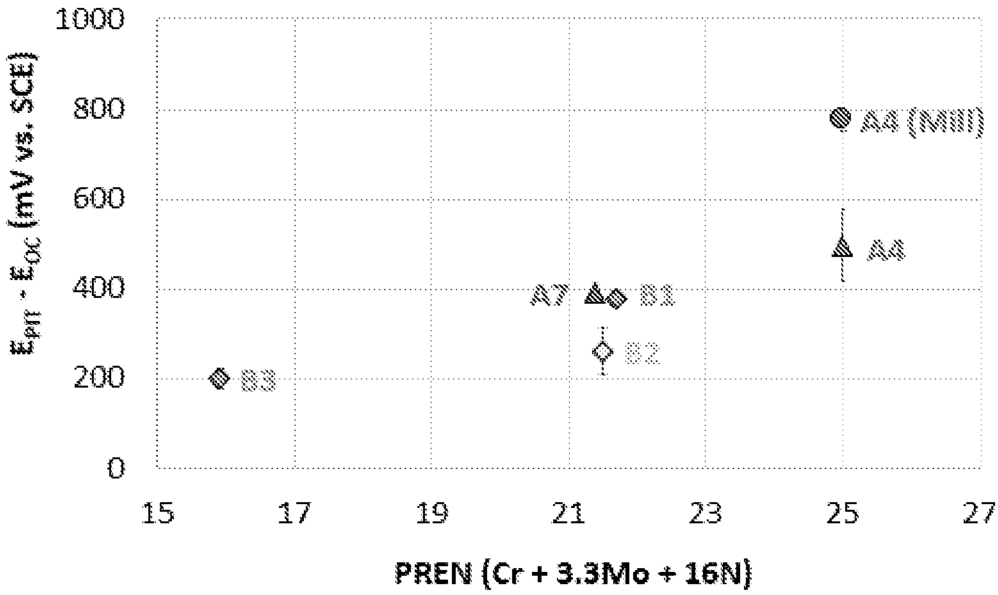


FIG. 15A

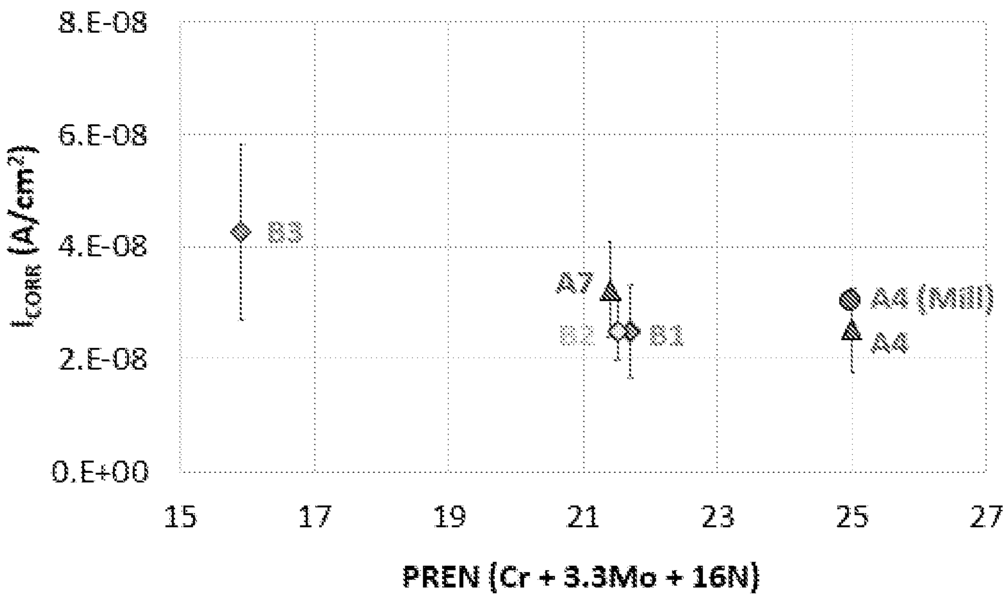


FIG. 15B

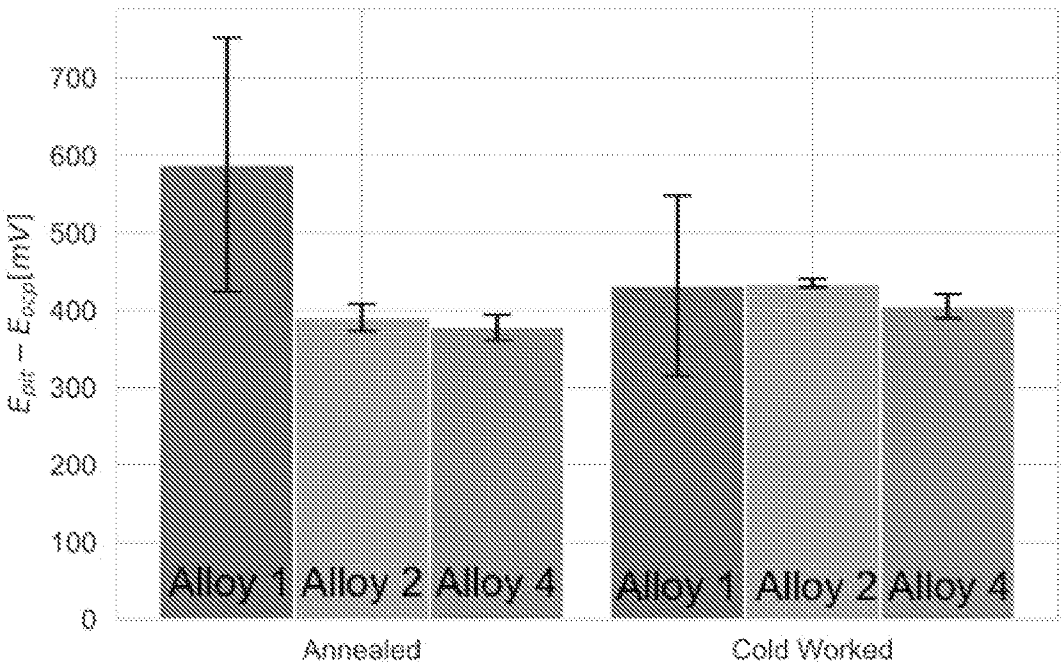


FIG. 16A

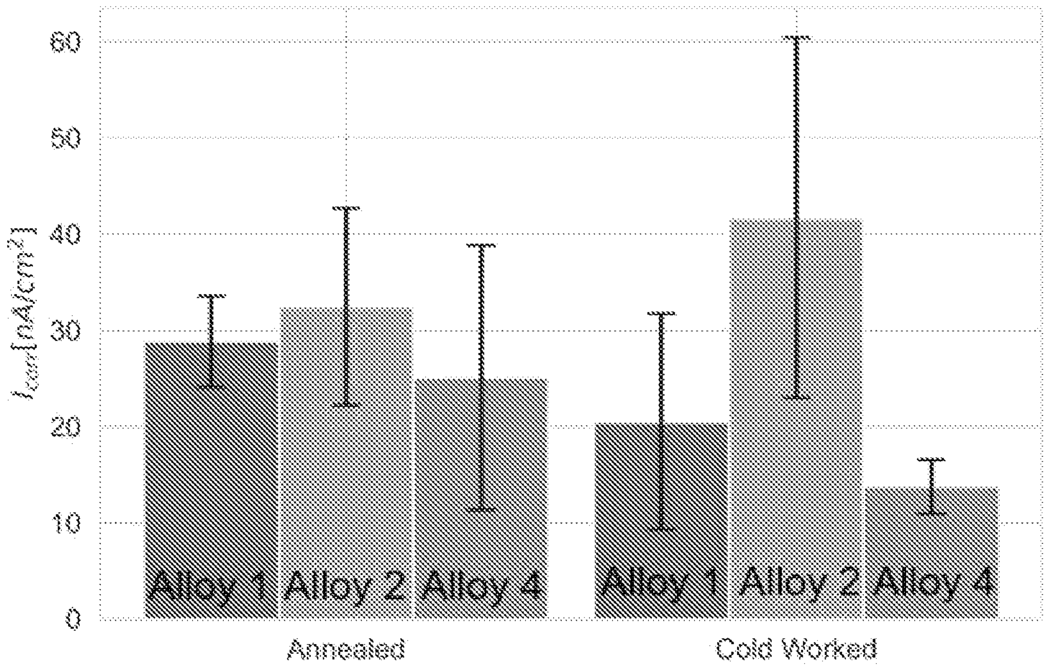


FIG. 16B

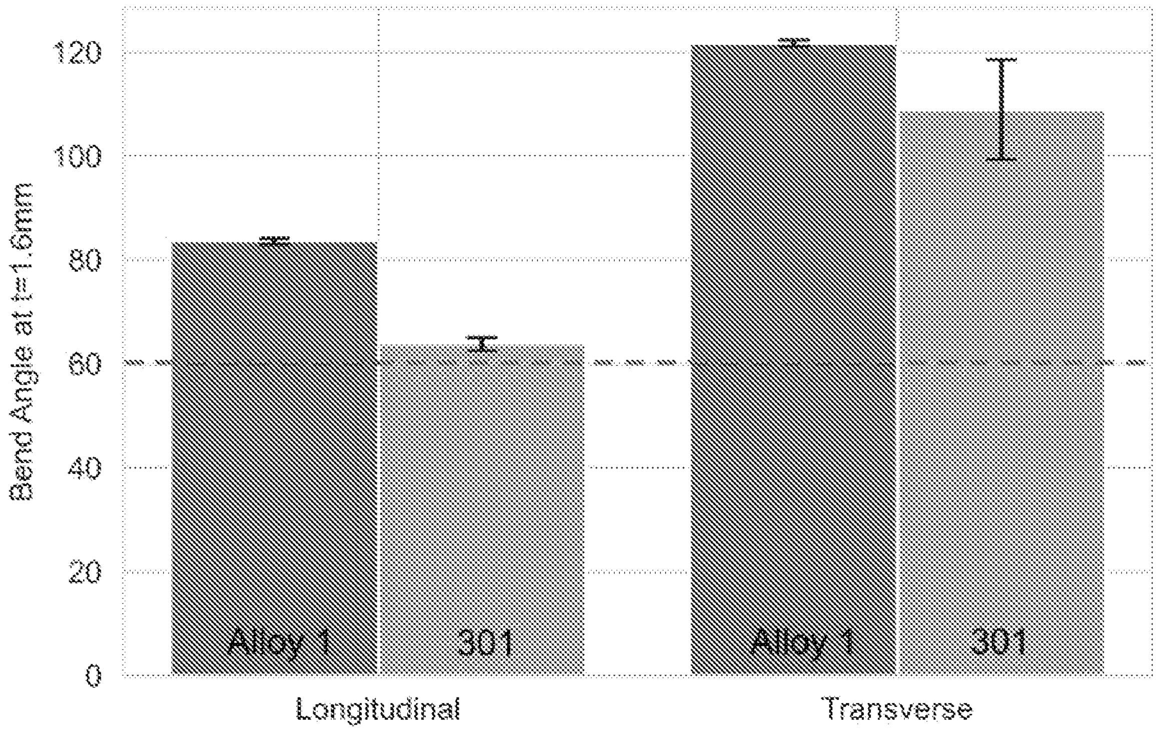

120
100
80
60
40
20
0
Bend Angle at t=1.6mm
Alloy 1
301
Alloy 1
301
Longitudinal
Transverse

FIG. 17

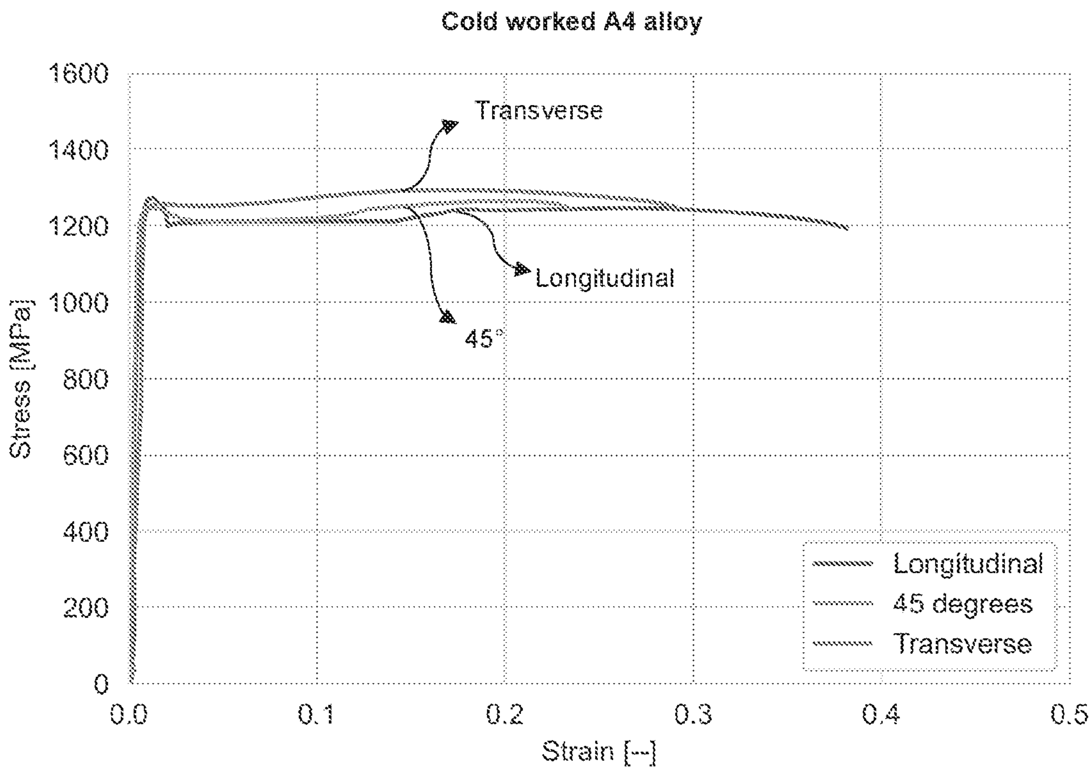

Cold worked A4 alloy
Transverse
Longitudinal
45°
Stress [MPa]
Strain [--]
1600
1400
1200
1000
800
600
400
200
0
0.0
0.1
0.2
0.3
0.4
0.5
Longitudinal
45 degrees
Transverse

FIG. 18

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2022/040501

A. CLASSIFICATION OF SUBJECT MATTER
INV. C22C38/42 C22C38/44 C22C38/58 C21D8/02 C22C38/00
C22C38/02 C22C38/04
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C22C C21D

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP H08 134596 A (NIPPON STEEL CORP) 28 May 1996 (1996-05-28) abstract; claims 1-9; tables 1-3 paragraph [0023]	1-27
X	JP H11 293405 A (HITACHI METALS LTD) 26 October 1999 (1999-10-26) abstract; claims 1-5; tables 1-2	1-27
X	JP H08 134595 A (NIPPON STEEL CORP) 28 May 1996 (1996-05-28) abstract; claims 1-7; tables 1-3	1-27

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

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

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

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
1 November 2022	10/11/2022

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

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2022/040501

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
JP H08134596 A	28-05-1996	NONE	
JP H11293405 A	26-10-1999	JP 4207137 B2	14-01-2009
		JP H11293405 A	26-10-1999
JP H08134595 A	28-05-1996	NONE	