Microstructure – As-Cast, Cold Worked and Annealed, Hot Worked and Annealed and Heat Treated (Part 1)

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Solidification
Macrostructure
Macrostructure of a VIM (vacuum induction melted) ingot of Fe-52% Ni alloy. A slice was cut transverse to the ingot axis and hot acid etched (50% HCl at 70 °C) revealing the solidification pattern. There is a very thin surface zone of small grains. Below the surface, there is a zone of columnar grains and the central portion is equiaxed but coarse. The scale is in inches.
Macrostructure of 5-inch square (127 mm) continuously cast billets of type 430 stainless steel (Fe - 0.03% C – 0.34% Mn – 0.48% Si – 17.78% Cr – 0.26% Ni – 0.05% Mo – 0.07% Cu) taken at three random locations along the strand. The discs were cut transverse to the growth direction and were hot acid etched. Note the thin region of fine grains at the surface, the large columnar zone and the central equiaxed zone (of varying coarseness). Note that there are some fine cracks present.
Macrostructure of 9-inch (229 mm) square continuously cast discs of type 316 austenitic stainless steel (Fe < 0.08% C – 17% Cr – 12% Ni – 2.5% Mo) after hot acid etching. Discs cut transverse to the growth direction (strand axis). There is a very thin surface layer of equiaxed grains and the columnar grains go to the center. There is no central equiaxed grain zone.
Macrostructure of 6-inch square (152 mm) continuously cast type 303 austenitic stainless steel (Fe - <0.15% C - >0.15% S – 18% Cr – 9% Ni – <0.6% Mo) taken at random along the strand length parallel to the strand length. Note that there is a shallow surface zone of fine equiaxed grains and the columnar zone goes all the way to the center, where there is a shrinkage cavity (left disc, red arrow). A stirring line (light etching line due to disturbing the columnar growth with magnetic stirring) can be seen in each (see arrows). The disc on the right was cut just off the centerline, so the central shrinkage cavity was missed.
Macrostructure of directionally solidified Ni-base eutectic alloy (etched with 1 mL H$_2$O$_2$ and 99 mL HCl, courtesy of W. Yankausas, TRW, Inc.)
Scanning electron microscope view of dendrites on the surface of a type 304 austenitic stainless steel electron-beam melt button (Robinson backscattered electron detector, original at 230X magnification).
As-Cast Microstructures
Dendritic structure of permanent mold cast A356 aluminum revealed using Weck’s reagent (viewed with polarized light and sensitive tint, 50X)
As-continuously cast (concast) 3004 aluminum (Al – 1.25% Mn – 1.05% Mg) tint etched with Weck’s reagent and viewed with crossed polarized light plus sensitive tint. Magnification bar is 50 µm long. Reveals segregation (“coring”) within the dendrites and intermetallics between the dendrites.
As-cast 206 aluminum (Al – 4.4% Cu – 0.3% Mg – 0.3% Mn) tint etched with Weck’s reagent and viewed with crossed polarized light plus sensitive tint. Magnification bar is 50 µm long.
As-cast 319 aluminum (Al – 6.0% Si – 3.5% Cu) tint etched with Weck’s reagent and viewed with crossed polarized light. Magnification bar is 100 µm long.
Dendritic microstructure of phosphorous-deoxidized copper (Cu – 0.02% P) in the as-cast condition revealed by Klemm’s I reagent (original at 50X in bright field illumination). Magnification bar is 200 µm long.
As-cast hypoeutectic Cu – 4.5% P tint etched with potassium dichromate reagent which colors the copper-rich proeutectic dendrites and the alpha-copper portion of the eutectic. Note that the color variations indicate compositional differences in the growing dendrites. Between the Cu dendrites is the eutectic of copper (colored) and copper phosphide, Cu$_3$P (white). Original at 200X.
As-cast eutectic Cu – 8.4% P tint etched with potassium dichromate reagent which colored the alpha-copper portion of the eutectic of alpha copper and copper phosphide, Cu$_3$P (white). Original at 200X.
As-cast hypereutectic Cu – 10.5% P tint etched with Klemm’s II reagent which colors the α-copper phase in the eutectic of Cu and copper phosphide. The large white particles are proeutectic copper phosphide, Cu₃P and the white, unetched part of the eutectic is copper phosphide. Original at 500X.
Microstructure of sand-cast Cu – 4% Sn etched with Beraha’s PbS tint etch revealing the dendritic cast structure. 63 HV.
Microstructure of sand cast Cu – 37% Zn revealing some beta phase between the alpha dendrites using Nomarski DIC and an as-polished specimen.
Microstructure of sand cast Cu – 42% Zn revealed using Beraha’s PbS tint etchant. Note the change in beta-phase morphology with the heat treatment.
Dendrites in as-cast Monel (Ni – 30% Cu) revealed using Beraha’s reagent (50 mL water – 50 mL HCl – 2 g ammonium bifluoride – 1 g potassium metabisulfite). Originals at 50X (left) and 100X (right). Magnification bars are 200 and 100 µm long, respectively.
Dendritic structure of cast IN-738 alloy (Ni – 0.17C – 16Cr – 8.5Co – 2.6W – 1.75 Mo – 0.9Nb – 1.75Ta – 3.4Al – 0.01B – 0.1Zr).
Dendritic cast structure of IN 738 etched with 60% HCl and viewed in bright field.
Left: 50x; right: 100x.
Dendritic solidification structure in cast Russian alloy CNK7 (Ni – 0.08C – 15Cr – 9Co – 7W – 0.4Mo – 3.5Ti – 4.2Al – 0.01B – 0.02Ce).
Dendritic cast structure of CNK-7 Ni-base superalloy etched with 60% HCl and viewed with polarized light plus sensitive tint, 50x.
Dendritic microstructure of Alloy 718 in the as-cast condition after tint etching with Beraha’s reagent. The white particles are Laves phase. The magnification bar is 200 µm long.
Dendritic structure of cast MAR-M247 alloy.
Acicular ferrite (arrows) in an as-cast low-carbon steel (Fe – 0.09% C – 0.39% Mn – 0.04% Si – 0.068% Al) revealed by Klemm’s I reagent (viewed with crossed polarized light plus sensitive tint). Original at 100X magnification.
Dendritic as-cast microstructure of Fe – 0.2% C – 0.6% Mn – 0.1% Si carbon steel etched with 2% nital and viewed with bright field illumination. Left: 50x; right: 100x.
As-cast Hadfield Mn steel, solution annealed at 1900°F (1038°C), and aged at 1065°F (575°C) which precipitated carbides at the austenite grain boundaries; etched with 10% sodium metabisulfite, 200X.
Microstructure of as-cast and annealed HP9-4-20 alloy steel (Fe – 0.19C – 0.3Mn – 8.83Ni – 4.46Co – 0.76Cr – 1.01Mo – 0.09V etched with 2% nital (left) and with Beraha’s sulfamic acid reagent number 4 (right). Note the grain boundary running horizontally (arrow, right).
Acicular microstructure of as-cast Fe – 2.95% C – 0.61% Mn – 29.3% Cr etched with Beraha’s sulfamic acid (3-2-1) reagent and viewed with bright field, 200x.
Dendritic structure of as-cast M-50 bearing steel (Fe – 0.8% C – 4% Cr – 1% V – 4.5% Mo) after VAR (vacuum arc remelting) revealed by modified Beraha’s reagent (300 mL water – 1 mL HCl – 2.5 g ammonium bifluoride – 0.5 g potassium metabisulfite). Original at 20X (magnification bar is 500 µm long).
Well-formed flakes of graphite in gray cast iron. As-polished; original at 200X.
Eutectic cells in gray cast iron revealed by etching with Klemm’s I reagent and enhanced by using polarized light with sensitive tint. Original at 50X magnification.
Microstructure of pearlitic gray cast iron tint etched with Beraha’s CdS reagent. Original at 500X.
Shrinkage cavities in white cast iron. Note the dendritic appearance as there was not enough liquid metal to fill in the interdendritic region. Original magnifications are 200X (left) and 500X (right). Etched with 2% nital.
Microstructure of white cast iron revealed using 2% nital and consisting of lamellar pearlite and cementite (white). Original at 1000X.
Microstructure of Ni-Hard cast iron (Fe – 3.3% C – 0.9% Mn – 0.9% Si – 1.8% Cr – 4.4% Ni – 0.4% Mo) revealing massive cementite (C), Ledeburite (arrows) and patches of plate martensite and retained austenite. Etched with aqueous 10% Na$_2$S$_2$O$_5$. Original at 500X. Ledeburite is the eutectic of cementite and austenite where, with cooling, the austenite usually transforms to ferrite and cementite in the form of pearlite (not in this case due to the high alloy content). Some graphite (G) is also present.
Ledeburite in a white cast iron (Fe – 4.0% C – 0.3% Si – 0.16% Mn – 0.91% Cr) etched with Beraha’s sulfamic acid reagent (100 mL water, 3 g K₂S₂O₅ and 2 g NH₂SO₃H). Original at 500X magnification. Taken in polarized light with sensitive tint.
Two clusters of spheroidal graphite nodules in austempered ductile iron. Viewed with crossed polarized light plus sensitive tint. Original at 500X.
Microstructure of pearlitic ductile iron revealed using Beraha’s CdS tint etch. Note the ferrite rings (“bull’s eyes”) around the nodules or nodule clusters. Viewed with polarized light plus sensitive tint. Original at 500X.
Microstructure of a fully ferritic ductile iron specimen. The specimen was etched with 2% nital and the magnification bar is 100 µm long.
Heat treated ductile cast iron tint etched with Beraha’s CdS film reagent and viewed with polarized light plus sensitive tint. Note the oddly-shaped graphite nodule (bottom, center) and the white (not colored) cementite particles. The martensite is colored blue and brown and there are small patches of (white) retained austenite between martensite “needles”. Original at 1000X.
Microstructure of austempered ductile iron tint etched with Beraha’s CdS reagent containing large graphite nodules (arrow), bainite (blue and brown), also called “ausferrite” and retained austenite (white) when viewed with polarized light plus sensitive tint. Original at 500X.
Temper nodules of graphite in malleable cast iron after a ferritizing anneal. The ferrite matrix was colored using Beraha’s sulfamic acid reagent (original at 500X in crossed polarized light plus sensitive tint). Magnification bar is 20 µm long.
As-cast Nihard cast iron (Fe – 2.98% C – 0.64% Mn – 0.85% Si – 4.4% Ni – 2.34% Cr) containing cementite (white), retained austenite (light brown), manganese sulfides (gray particles) and plate martensite “needles” (light blue and medium blue) after tint etching with Beraha’s CdS reagent and viewing with polarized light plus sensitive tint. Original at 1000X.
Alloyed white cast iron (Fe – 2.2% C – 0.9% Mn – 0.5% Si – 12.7% Cr – 0.4% Mo – 0.1% V) with a martensitic matrix and a network of eutectic alloy carbides (white). Etched with Vilella’s reagent. Original at 200X.
Power Metallurgy
Sponge Fe Powder

SEM views of sponge iron powder before compaction.
Polished sponge iron particles etched with 2% nital to reveal the ferrite grain boundaries.
Fe Powder Sintered 2050 °F – 2 min

As-polished specimens showing the distribution and size of the voids.
Ferrite grain structure observed after etching with 2% nital. Some of the black-looking voids are un-reacted graphite.
Fe Powder Sintered 2050 °F – 5 min

As-polished (left) and etched (right, 2% nital) examples of the microstructure after sintering 5 minutes.
Fe Powder Sintered 2050 °F – 10 min

As-polished (left) and etched (right, 2% nital) examples of the microstructure after sintering 10 minutes.
Fe Powder Sintered 2050 °F – 20 min

As-polished (left) and etched (right, 2% nital) examples of the microstructure after sintering 20 minutes
Fe Powder Sintered 2050 °F – 30 min

As-polished (left) and etched (right, 2% nital) examples of the microstructure after sintering 30 minutes
CCM PLUS Co-Cr-Mo Powder

SEM views of Co-Cr-Mo powder before compaction.
Dendritic solidification structure of polished CCM PLUS powder particles etched with a 10:1 mix of HCl and H$_2$O$_2$ (3 % conc.).
As-hip’ped (hot isostatically pressed) CCM Plus Co-Cr-Mo alloy, etched with a 10:1 mixture of HCl – H₂O₂ (3% conc.)
CCM PLUS Co-Cr-Mo

2.5-inch Diam, As-Forged Bar  1.5-inch Diam., As-Rolled Bar

CCM Plus Co-Cr-Mo alloy bar, etched with a 10:1 mixture of HCl – H₂O₂ (3% conc.)
Microstructure of as-hipped (hot isostatically pressed) powder-metallurgy (P/M) René 95 alloy (Ni – 0.15C – 8Co – 14Cr – 3.5Mo – 3.5W – 2.5Ti – 3.5Al – 3.5Nb) revealing grain boundary carbides and coarse gamma prime in an austenitic matrix after etching with glyceregia.
Microstructure of as-hipped (hot isostatically pressed) P/M René 95 alloy revealing grain boundary carbides and coarse gamma prime in an austenitic matrix after etching with glyceregia. Prior-particle shapes are clearly visible at low magnification.
Hot Worked Microstructures
Hot Working

Hot working occurs at a temperature that is relatively close to the melting point of the metal or alloy. This temperature is normally well above the recrystallization temperature. A homogenization cycle may be used, particularly with highly alloyed compositions, prior to hot working to permit alloy diffusion and enhance chemical homogeneity. Too high a temperature must be avoided so that “burning” or grain-boundary liquation (incipient melting) does not occur.

The temperature during the last hot working pass is also important as it controls the grain size in the as-rolled microstructure and may influence problems such as “banding” in steels. If the finishing temperature is low, recrystallization will not occur and the grain structure will be coarse and elongated and will contain residual deformation (dislocations). “Warm” working occurs below the recrystallization temperature.
Microstructure of hot rolled Fe – 0.046% C – 0.36% Mn - <0.01% Si – 0.061% Al carbon steel with a finishing temperature of 1600 °F (871 °C). Note the equiaxed ferrite grains and pearlite patches. No deformation is present in the ferrite phase. Etched with 2% nital; originals at 500X (magnification bars are 20 µm long).
Microstructure of hot rolled Fe – 0.046% C – 0.36% Mn - <0.01% Si – 0.061% Al carbon steel with a finishing temperature of 1400 °F (760 °C). Note the nearly equiaxed ferrite grains and pearlite patches. Some residual deformation is visible in the transverse specimen. Etched with 2% nital; originals at 500X (magnification bars are 20 µm long).
Microstructure of hot rolled Fe – 0.046% C – 0.36% Mn - <0.01% Si – 0.061% Al carbon steel with a finishing temperature of 1200 °F (649 °C). Note the elongated ferrite grains and small pearlite patches. The ferrite grains contain considerable residual deformation Etched with 2% nital; originals at 500X (magnification bars are 20 µm long).
Microstructure of hot rolled Fe – 0.046% C – 0.36% Mn - <0.01% Si – 0.061% Al carbon steel with a finishing temperature of 1000 °F (538 °C). Note the highly elongated ferrite grains and small pearlite patches. There is considerable deformation in the ferrite. Etched with 2% nital; originals at 500X (magnification bars are 20 µm long).
Microstructure of hot rolled Fe – 0.11% C – 0.50% Mn - <0.01% Si – 0.066% Al carbon steel with a finishing temperature of 1600 °F (871 °C). Note the equiaxed ferrite grains and pearlite patches (top – longitudinal plane, bottom – transverse plane). No deformation is present in the ferrite phase. Etched with 2% nital; originals at 500X (magnification bars are 20 µm long).
Microstructure of hot rolled Fe – 0.11% C – 0.50% Mn - <0.01% Si – 0.066% Al carbon steel with a finishing temperature of 1400 °F (760 °C). Note the nearly equiaxed ferrite grains and elongated pearlite patches. Some deformation is visible in the ferrite, particularly in the transverse specimen. Etched with 2% nital; originals at 500X (magnification bars are 20 µm long).
Microstructure of hot rolled Fe – 0.11% C – 0.50% Mn - <0.01% Si – 0.066% Al carbon steel with a finishing temperature of 1200 °F (649 °C). Note the elongated ferrite grains and elongated pearlite patches. Considerable deformation is visible in the ferrite phase. Etched with 2% nital; originals at 500X (magnification bars are 20 µm long).
Microstructure of hot rolled Fe – 0.11% C – 0.50% Mn - <0.01% Si – 0.066% Al carbon steel with a finishing temperature of 1000 °F (538 °C). Note the elongated ferrite grains and elongated pearlite patches. Considerable deformation is visible in the ferrite phase. Etched with 2% nital; originals at 500X (magnification bars are 20 µm long).
Microstructure of hot rolled Fe – 0.22% C – 0.99% Mn - 0.02% Si – 0.059% Al carbon steel with a finishing temperature of 1600 °F (871 °C). Note the equiaxed ferrite grains and pearlite patches. No deformation is visible in the ferrite phase. Etched with 2% nital; originals at 500X (magnification bars are 20 µm long).
Microstructure of hot rolled Fe – 0.22% C – 0.99% Mn - 0.02% Si – 0.059% Al carbon steel with a finishing temperature of 1400 °F (760 °C). Note the equiaxed ferrite grains and banded (layered) pearlite. No deformation is visible in the ferrite phase. Etched with 2% nital; originals at 500X (magnification bars are 20 µm long).
Microstructure of hot rolled Fe – 0.22% C – 0.99% Mn - 0.02% Si – 0.059% Al carbon steel with a finishing temperature of 1200 °F (649 °C). Note the elongated ferrite grains and banded (layered) pearlite patches. Little deformation is visible in the ferrite phase. Etched with 2% nital; originals at 500X (magnification bars are 20 µm long).
Hot Working with 1000 °F Finishing Temperature

Fe – 0.22% C Steel

Microstructure of hot rolled Fe – 0.22% C – 0.99% Mn - 0.02% Si – 0.059% Al carbon steel with a finishing temperature of 1000 °F (538 °C). Note the elongated ferrite grains and banded (layered) pearlite patches. Substantial deformation is visible in the ferrite phase. Etched with 2% nital; originals at 500X (magnification bars are 20 µm long).
Microstructure of hot forged, quenched and tempered HP9-4-20 alloy steel (Fe – 0.19C – 0.3Mn – 8.83Ni – 4.46Co – 0.76Cr – 1.01Mo – 0.09V etched with 2% nital (left) and with Beraha’s sulfamic acid reagent number 4 (right). (Compare these images with previously shown as-cast images)
Cold Worked & Annealed Microstructures
Cold working occurs at temperatures below the recrystallization temperature. Typically, it is performed at room temperature. For low-melting point metals and alloys, deformation at room temperature can be above the recrystallization temperature. There are a variety of cold working methods, such as rolling, swaging, extrusion and drawing. Cold worked structures normally exhibit deformed grain structures with considerable slip (bcc and fcc metals) or mechanical twinning (hcp metals).
Annealing is a process where the metal is heated to a temperature sufficient to fully recrystallize a cold worked microstructure. In steels, annealing may be performed on a hardened steel to return it to a soft condition suitable for machining. Tool steels are usually given a special annealing process to spheroidize the carbide, which minimizes its hardness. Certain Fe-based alloys may be given special annealing practices to improve electrical or magnetic behavior.
Microstructure of low-carbon (0.003%) sheet steel with no deformation (top) and after 10% reduction in thickness. Note the slight elongation of the grains after 10% reduction. Longitudinal planes are shown after etching with 2% nital. A few inclusions and carbides are also present. Original micrographs at 500X magnification. Magnification bars are 20 µm long.
Microstructure of low-carbon (0.003%) sheet steel with 20% (top) and 30% (bottom) reduction in thickness. Note the slight elongation of the grains after reduction. Longitudinal planes are shown after etching with 2% nital. A few inclusions and carbides are also present. Slip lines are noticeable after 30% deformation. Original micrographs at 500X magnification. Magnification bars are 20 µm long.
Microstructure of low-carbon (0.003%) sheet steel with 40% (top) and 50% (bottom) reduction in thickness. Note the increased elongation of the grains after reduction. Longitudinal planes are shown after etching with 2% nital. A few inclusions and carbides are also present. Slip lines are noticeable after deformation. Original micrographs at 500X magnification. Magnification bars are 20 µm long.
Microstructure of low-carbon (0.003%) sheet steel with 60% (top) and 70% (bottom) reduction in thickness. Note the increased elongation of the grains after heavy reduction. Longitudinal planes are shown after etching with 2% nital. A few inclusions and carbides are also present. Slip lines are quite noticeable after deformation. Original micrographs at 500X magnification. Magnification bars are 20 μm long.
Microstructure of low-carbon (0.003%) sheet steel with 80% (top) and 90% (bottom) reduction in thickness. Note the extreme elongation of the grains after very heavy reduction. Indeed, the grain boundaries have become hard to reveal with nital (longitudinal planes are shown after etching with 2% nital). A few inclusions and carbides are also present. Slip lines are very dense after deformation. Original micrographs at 500X magnification. Magnification bars are 20 µm long.
Sheared end of 6061-F (Al – 1% Mg – 0.6% Si – 0.2% Cr – 0.27% Cu) extruded rod electrolytically etched with Barker’s reagent (30 V dc, 2 min.) and viewed with polarized light plus sensitive tint revealing the heavily elongated grains from extruding and the compression of the sheared end. Magnification bar is 100 µm long.
Cu – 5% Sn – 0.15% P, Cold Drawn

Microstructure of wrought phosphor bronze, Cu – 5% Sn – 0.15% P, cold drawn revealing heavily cold-worked, elongated FCC grains (note slip lines). Tint etched with Klemm’s II. Original at 200X, polarized light and sensitive tint.
Microstructure of wrought, cold worked and annealed (600 °C, 1112 °F) Cu – 10% Zn. The structure, which is fully recrystallized, consists of FCC alpha grains and annealing twins. Tint etching reveals the grain structure much better than the potassium dichromate etch. Originals at 100X. 54 HV.
Microstructure of wrought, cold worked and annealed (750 °C, 1382 °F) Cu – 10% Zn. The structure consists of FCC alpha grains (with a duplex size distribution) and annealing twins. (Compare with 600 °C anneal)
Cold worked wrought alpha brass, Cu – 20% Zn. Note heavy slip lines in the alpha grains. Original at 100X. Swab etched with equal parts of NH₄OH and H₂O₂ (3% conc.).
Microstructure of Cu – 20% Zn, hot extruded, cold worked and annealed at 500 vs. 600 °C, revealing a variation in grain size. The specimens were tint etched with Beraha’s PbS reagent.
Wrought cartridge brass, Cu-30% Zn, cold reduced 30%, revealing cold worked FCC grains (note slip lines) and annealing twins. Tint etched with Klemm’s I reagent (original at 100X, crossed polarized light plus sensitive tint).
Wrought cartridge brass, Cu–30% Zn, cold reduced 50%, revealing heavily cold worked FCC grains (note slip lines) and annealing twins. Tint etched with Klemm’s I reagent (original at 100X, crossed polarized light plus sensitive tint).
Microstructure of wrought cartridge brass, Cu-30\% Zn, cold reduced 50\%, and annealed: 260 °C (500 °F) for 30 min. did not visibly alter the cold worked FCC grains (note slip lines) and annealing twins; 371 °C (700 °F) for 30 min. produced partial recrystallization. Tint etched with Klemm’s I reagent (Originals at 100X, crossed polarized light plus sensitive tint).
Microstructure of wrought cartridge brass, Cu – 30% Zn, cold reduced 50%, annealed at 427 °C (800 °F): 4 minutes did not visibly affect the cold worked grain structure (note heavy slip lines); 8 minutes has produced the start of recrystallization. Tint etched with Klemm’s I (Originals at 100X, crossed polarized light (off crossed) plus sensitive tint).
Microstructure of wrought cartridge brass, Cu – 30% Zn, cold reduced 50%, annealed at 427 °C (800 °F): 15 minutes has partially recrystallized the FCC grain structure with some remaining coarse cold worked grains; 30 minutes has increased the degree of recrystallization. Tint etched with Klemm’s I (originals at 100X, crossed polarized light (off crossed)).
Cu–30% Zn, HE, CR 50%, Annealed 482 °C

Microstructure of wrought cartridge brass, Cu – 30% Zn, cold reduced 50%, annealed at 482 °C (900 °F): – 15 min. has fully recrystallized the FCC grain structure, but it is duplex distribution; 60 min. has increased the grain size. Tint etched with Klemm’s III.
Microstructure of wrought cartridge brass, Cu – 30% Zn, cold reduced 50% and annealed at 704 °C (1300 °F) – 30 min. producing a fully recrystallized, and grown, equiaxed FCC grain structure with annealing twins. Polarized light and sensitive tint.
Microstructure of wrought aluminum brass, Cu – 22% Zn – 2% Al, cold drawn and annealed producing equiaxed alpha grains containing annealing twins. Tint etched with Beraha’s PbS.
Cu – 22% Zn – 2% Al, CD, Annealed at 850 °C

Microstructure of wrought aluminum brass, Cu – 22% Zn – 2% Al, annealed at 850°C (1562 °F) producing equiaxed alpha grains containing annealing twins. 57 HV; ASTM 00.
Annealed and cold drawn (“half-hard”) Everdur, Cu – 3% Si – 1% Mn, tint etched with Klemm’s I. Note that certain grains, with the same color and crystal orientation, have been lightly deformed compared to the rest. Original at 100X. Viewed with polarized light and sensitive tint.

Cu – 3% Si – 1% Mn, “Half Hard”
Cu – 40% Zn, “Muntz Metal”

504 °C – 1 h, Water Quench
649 °C – 1 h, Water Quench

Microstructure of Muntz Metal, Cu – 40% Zn (α-β brass) heated to various temperatures in the α+β phase field and quenched showing an increase in beta phase (colored) and a decrease in preferred orientation. Tint etched with Klemm’s I reagent (bright field).
Microstructure of Muntz Metal, Cu – 40% Zn, heated to 716 °C (1320 °F), held 1 h and water quenched producing still more beta phase (colored), of larger size, and with less preferred orientation. Nomarski DIC of this specimen tint etched with Klemm’s I reagent reveals the grain and twin structure in the un-etched alpha phase (not colored).
Microstructure of Muntz metal, Cu – 40% Zn, heated to 843 °C (1550 °F) into the beta field, held 1 hour, and air cooled. Note the three prior-beta grains transformed to alpha and ordered beta (same color within each beta grain) revealed by Klemm’s I reagent (bright field).
Elgiloy (Co-20% Cr-15% Fe-15% Ni-7% Mo-2% Mn -0.05% B-0.15% C) that was hot rolled and solution annealed producing partial recrystallization. Etched with 15 mL HCl – 10 mL acetic acid – 10 HNO₃, left: bright field, right: Nomarski DIC.
Microstructure of Elgiloy, a Co-based alloy used for watch springs (Co – 20% Cr – 15% Fe – 15% Ni – 2% Mn – 7% Mo – 0.05% B – 0.15% C) after hot rolling and solution annealing (1040 °C – 2 hours, water quenched). The specimen is partially recrystallized. The specimen was tint etched with Beraha’s IV plus 1 g FeCl₃ per 100 mL. The specimen was viewed with polarized light plus sensitive tint. The magnification bar is 100 µm long.
Elgiloy (Co-20% Cr-15% Fe-15% Ni-7% Mo-2% Mn –0.05% B-0.15% C) that was hot rolled and solution annealed producing partial recrystallization. Etched with 15 mL HCl – 10 mL acetic acid – 10 HNO₃, left: bright field, right: Nomarski DIC.
Microstructure of Elgiloy, a Co-based alloy used for watch springs after hot rolling and solution annealing (1090 °C – 2 hours, water quenched). The specimen is fully annealed. The specimen was tint etched with Beraha’s IV plus 1 g FeCl₃ per 100 mL. The specimen was viewed with polarized light plus sensitive tint. The magnification bar is 100 µm long.
Elgiloy, Hot Rolled + 1150 °C – 2 h, WQ

Elgiloy (Co-20% Cr-15% Fe-15% Ni-7% Mo-2% Mn -0.05% B-0.15% C) that was hot rolled and solution annealed producing full recrystallization. Etched with 15 mL HCl – 10 mL acetic acid – 10 HNO₃, left: bright field, right: Nomarski DIC.
Microstructure of Elgiloy, a Co-based alloy used for watch springs after hot rolling and solution annealing (1150 °C – 2 hours, water quenched). Note the annealing twins. The specimen was tint etched with Beraha’s IV plus 1 g FeCl₃ per 100 mL. The specimen was viewed with polarized light plus sensitive tint. The magnification bar is 100 µm long.
Elgiloy (Co-20% Cr-15% Fe-15% Ni-7% Mo-2% Mn –0.05% B-0.15% C) that was hot rolled and solution annealed producing full recrystallization. Etched with 15 mL HCl – 10 mL acetic acid – 10 HNO₃, left: bright field, right: Nomarski DIC.
Microstructure of L605 (Co – 0.1C – 10Ni – 20Cr – 15W – 1.5Mn – 0.5Si) after a 35% cold reduction (left) and then after solution annealing at 1149 °C (2100 °F) and revealed using 15 mL HCl-10 mL acetic acid-10 mL nitric acid. The magnification bars are both 50 µm long. L605 is also known as Haynes alloy 25.