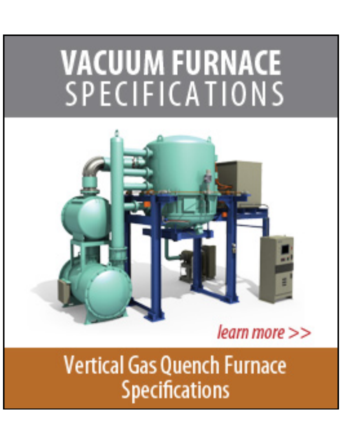
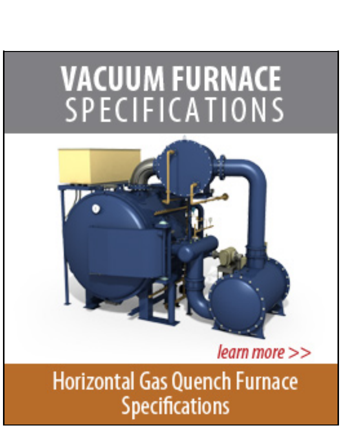
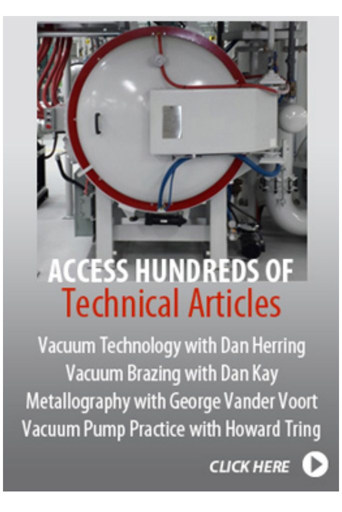






Deformation and Annealing of Cartridge Brass

May 11, 2015 by George Vander Voort

Abstract

Copper and its alloys are among the most malleable metals and alloys in existence. Cartridge brass, Cu – 30% Zn, has been used for many years to produce cartridge cases for ammunition due to its superior cold forming characteristics. This article shows the microstructure and hardness of cartridge brass from the fully annealed to the heavily cold worked condition. Then, it illustrates the influence of annealing temperature and time on removing the effect of the cold work and returning the alloy to a very low hardness annealed structure.

Introduction

Cartridge brass, Cu – 30% Zn, is a single-phase Cu-based alloy where the addition of zinc increases the strength of copper by solid solution strengthening. The maximum solubility of zinc in copper at ambient temperature is slightly above 30% Zn. Higher levels of Zn, for example, 40% Zn, produce two phased α-β brass which is less malleable than the single phase, α-Cu cartridge brass. Cartridge brass, as the name states, has been used for many years to make cartridges for bullets due to its excellent formability and good cold formed mechanical properties. As an example, Figure 1 shows the microstructure of the starting cup with an annealed α-Cu grain structure, exhibiting annealing twins, used to cold form cartridge cases. Figure 2 shows the firing pin end of a formed 338 caliber cartridge case revealing a heavily cold worked microstructure. Color etching is far more effective than black & white etching to reveal the complete grain structure and deformation. Comparisons of color vs. B&W etching will be presented later.

Experiment

Specimens of hot extruded and fully annealed cartridge brass were cold reduced 15, 30, 40, 50, 60 and 70% in thickness. Specimens were mounted and polished and etched using the commonly used B&W etchant of equal parts of ammonium hydroxide and hydrogen peroxide (3% conc.) mixed fresh and used by swabbing. Figures 3 a and b, 3 e and f, and 3 i and j show B&W images of longitudinal planes from the annealed (Fig. 3 a) and the cold worked cartridge brass specimens (30, 40, 50, 60 and 70% cold reductions). Figures 3 c and d, 3 g and h, and 3 k and l show color images using Klemm's III tint etch and polarized light for the cold worked specimens (15, 30, 40, 50, 60 and 70% cold reductions). These images reveal that the grains are becoming elongated with cold reduction, with increasing length/width ratio with increasing cold reduction, plus greater amounts of slip deformation. Figure 4 shows the increase in Vickers hardness (100 gf load) from 57.9 ± 4.8 HV in the starting fully annealed condition to 231.9 ± 7.9 HV after a 70% cold reduction in thickness, a fourfold increase in hardness.

Annealing experiments were conducted on a number of the cold worked specimens. Figures 5a and b show color etched images of the specimens cold reduced 50% and then annealed 30 minutes at 500 and 700°F. No difference in the microstructure is seen in the specimen held 30 minutes at 500°F while a very small amount of recrystallization is observed in the specimen held 30 minutes at 700°F. Figures 6a and b show color images of 50% cold reduced specimens held for 4 and 8 minutes at 800°F while Figures 6c and d show 50% cold reduced specimens held 15 and 30 minutes at 800°F. No change is observed after 4 minutes at 800°F, while a minor amount of recrystallization has occurred after 8 minutes. Holding specimens for 15 and 30 minutes at 800°F revealed partial recrystallization after 15 minutes and full recrystallization after 30 minutes. The grain structure is relatively fine but is not uniform in its distribution.

Figures 7a and b illustrate the grain structure in color after 15 and 30 minutes at 900°F. The 15 minute hold produced a non-uniform grain structure while the 60 minute hold produced better results although the grain size distribution appears to be duplex. Figures 8a and b show a B&W and a color image (Klemm's I reagent) after annealing 30 minutes at 1300°F which produced a fully recrystallized, uniform grain size distribution but coarse grained (as in Figs. 1 and 3a). Figures 8c and d show the same specimen but color tint etched using Klemm's III and Beraha's PbS tint etchants. Both are excellent for use with cartridge brass. Tint etchants also reveal details about the presence, or absence, of crystallographic texture. We note that as the cartridge brass is cold reduced greater amounts the grain coloring becomes more monotone, while when the annealing temperature is increased resulting in fully recrystallized grains with increasing size, the coloring becomes more variable with a random distribution of the colors. A random dispersion of a broad range of colors indicates that we have a random crystallographic texture while a narrow color range suggests that we have a preferred texture.

Vickers indents, 100 at a 100 gf load, were made on the original hot extruded and fully mill-annealed starting material and on the hot extruded, annealed and 50% cold reduced specimen and for similar 50% CR specimens that were annealed for 30 minutes at 500, 700, 800, 900 and 1300°F. Note that the distribution curves for the 50% CR specimen and the 50% CR specimen held at 500°F for 30 minutes are essentially identical, which is not surprising based on the image in Figure 5a which shows no influence of annealing at 500°F on the microstructure. As the annealing temperature increased from 700 to 1300°F, the HV distribution curves become more peaked and the hardness decreases. The distribution curve for the starting fully annealed specimen is the lowest in hardness as 30 minutes at 1300°F yielded slightly greater hardness. Figure 10 plots the mean Vickers hardness for each of the 50% CR specimens from the initial non-annealed condition (plotted at ambient temperature) versus the 30 minute hold at each annealing temperature from 500 to 1300°F.

Conclusions

The experiment illustrates the extreme malleability of cartridge brass, Cu – 30% Zn, which has been used for many years to build cartridge cases for bullets. Cold working increases the hardness of the alloy dramatically; a 400% increase was obtained going from the fully annealed condition to a 70% reduction in thickness. The grains become thinner and more elongated with increased cold reduction – anisotropic in grain shape. Along with the increased strength, the cartridge brass remains ductile enough to provide good service performance. The re-annealing experiments showed how recrystallization begins slowly, and with duplex appearing grain size distributions until the recrystallization temperature becomes quite high resulting in a coarse grained twinned structure with a uniform grain size distribution. The results also demonstrate the value of color tint etchants for revealing the microstructure fully and for revealing preferred versus random crystallographic textures.

Starting Annealed Microstructure of Cu-30% Zn Cup

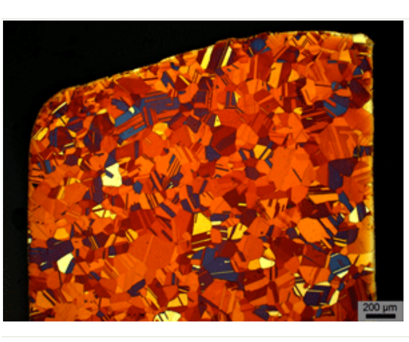


Figure 1. Initial annealed microstructure of a cartridge brass cup to be cold drawn into a cartridge for large size bullets. The OD surface is at left and the ID surface is at the right; transverse orientation (Klemm's III color etch, polarized light, 50X).

Cold Work at Firing Pin of a 338 Caliber Cartridge Case

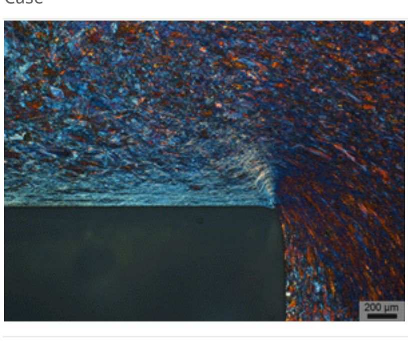
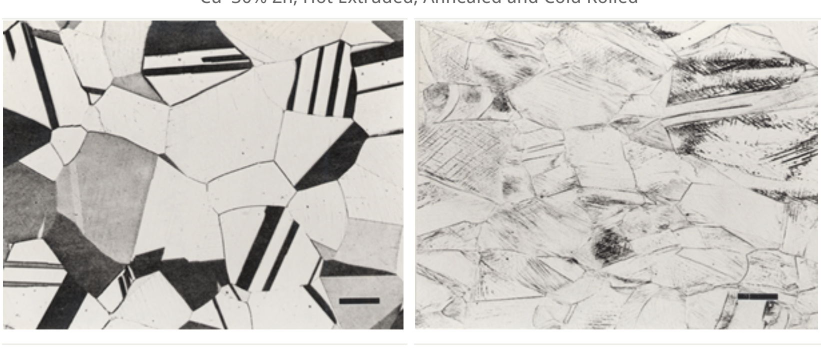


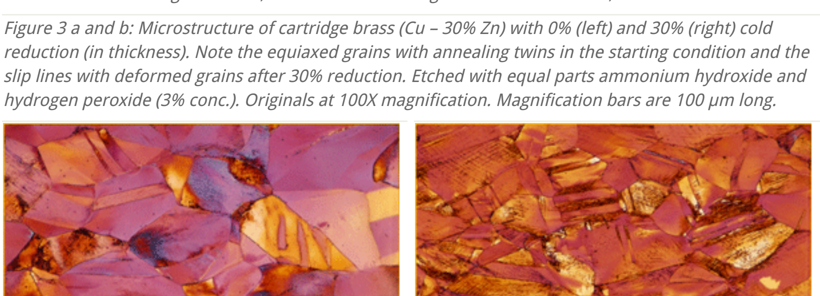
Figure 2: Heavily cold worked structure at the firing pin region of a 338 caliber cartridge case (Klemm's III, polarized light, 50X).

Cu–30% Zn, Hot Extruded, Annealed and Cold Rolled



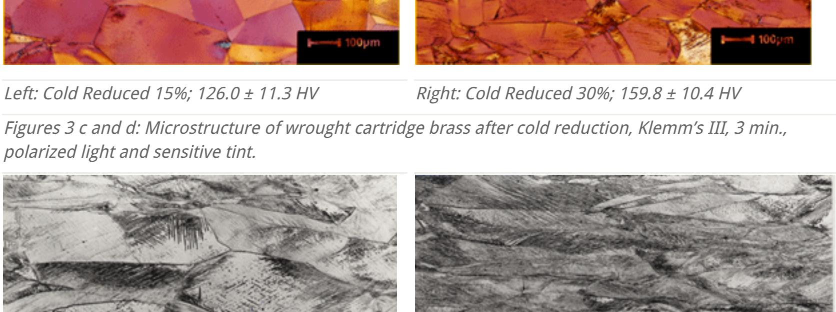
Left: Annealed Starting Condition; 57.9 ± 4.8 HV Right: Cold Reduced 30%; 159.8 ± 10.4 HV

Figure 3 a and b: Microstructure of cartridge brass (Cu – 30% Zn) with 0% (left) and 30% (right) cold reduction (in thickness). Note the equiaxed grains with annealing twins in the starting condition and the slip lines with deformed grains after 30% reduction. Etched with equal parts ammonium hydroxide and hydrogen peroxide (3% conc.). Originals at 100X magnification. Magnification bars are 100 μm long.



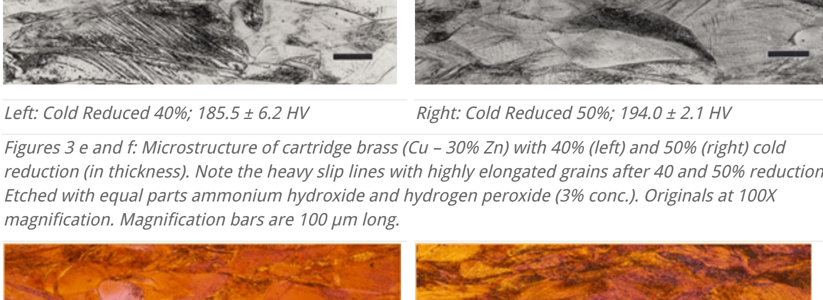
Left: Cold Reduced 15%; 126.0 ± 11.3 HV Right: Cold Reduced 30%; 159.8 ± 10.4 HV

Figures 3 c and d: Microstructure of wrought cartridge brass after cold reduction, Klemm's III, 3 min., polarized light and sensitive tint.



Left: Cold Reduced 40%; 185.5 ± 6.2 HV Right: Cold Reduced 50%; 194.0 ± 2.1 HV

Figures 3 e and f: Microstructure of cartridge brass (Cu – 30% Zn) with 40% (left) and 50% (right) cold reduction (in thickness). Note the heavy slip lines with highly elongated grains after 40 and 50% reduction. Etched with equal parts ammonium hydroxide and hydrogen peroxide (3% conc.). Originals at 100X magnification. Magnification bars are 100 μm long.

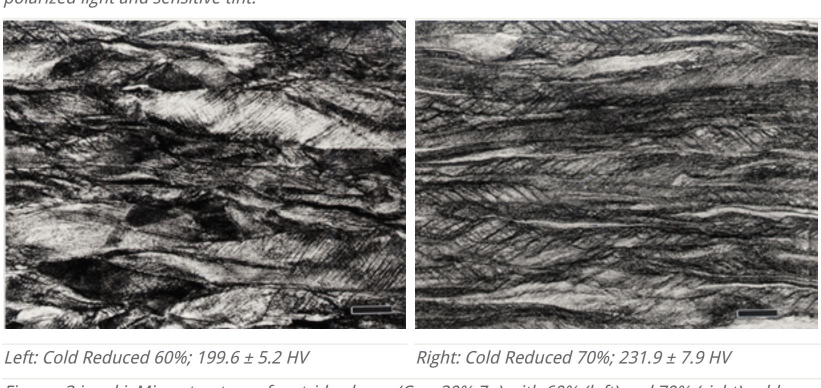


Left: Cold Reduced 40%; 185.5 ± 6.2 HV Right: Cold Reduced 50%; 194.0 ± 2.1 HV

Figures 3 g and h: Microstructure of wrought cartridge brass after cold reduction, Klemm's III, 3 min., polarized light and sensitive tint.

Left: Cold Reduced 60%; 199.6 ± 5.2 HV Right: Cold Reduced 70%; 231.9 ± 7.9 HV

Figures 3 i and j: Microstructure of cartridge brass (Cu – 30% Zn) with 60% (left) and 70% (right) cold reduction (in thickness). Note the very dense slip lines with highly elongated grains after 60 and 70% reduction. Etched with equal parts ammonium hydroxide and hydrogen peroxide (3% conc.). Originals at 100X magnification. Magnification bars are 100 μm long.



Left: Cold Reduced 60%; 199.6 ± 5.2 HV Right: Cold Reduced 70%; 231.9 ± 7.9 HV

Figures 3k and l: Microstructure of wrought cartridge brass after cold reduction, Klemm's III, 3 min., polarized light and sensitive tint.

Influence of Cold Reduction on Hardness of Cu – 30% Zn

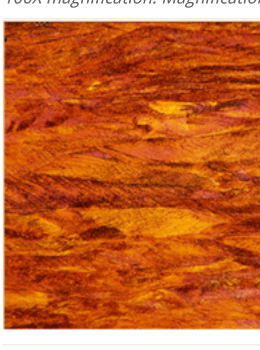


Figure 4: Cold reduction to 70% of the original thickness caused a fourfold increase in Vickers hardness.

HV of Cold Worked and Annealed Cu-30% Zn

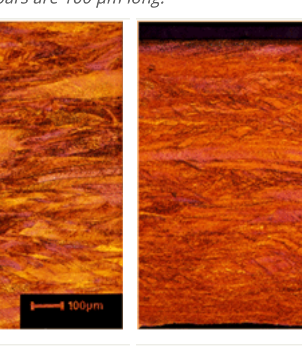


Figure 9: The fully annealed specimen was cold reduced 50% in thickness. Then, CR specimens were annealed for 30 minutes at 500, 700, 800, 900 and 1300°F. Cross sections were prepared metallographically and 100 HV indents at 100 gf load were made in each. The plot shows the distribution of HV values for each specimen.

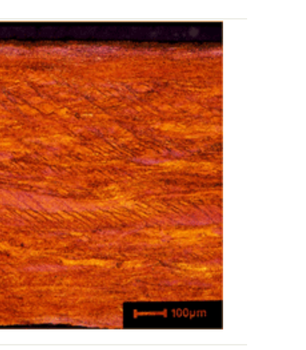
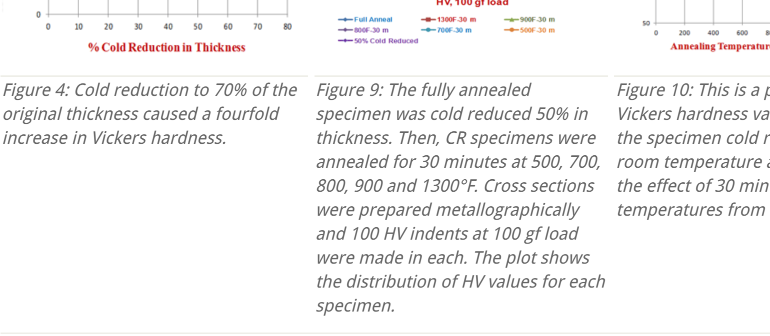


Figure 10: This is a plot of the mean Vickers hardness values starting with the specimen cold reduced 50% at room temperature and then showing the effect of 30 minutes time at temperatures from 500 to 1300°F.

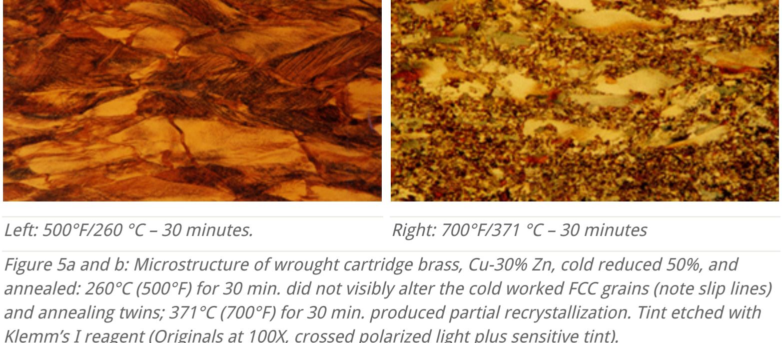
Cu–30% Zn, Hot Ext., Cold Red. 50%, Annealed



Left: 500°F/260 °C – 30 minutes. Right: 700°F/371 °C – 30 minutes

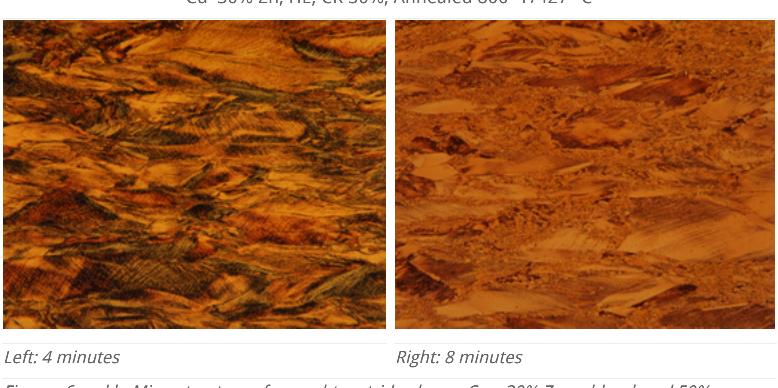
Figure 5a and b: Microstructure of wrought cartridge brass, Cu-30% Zn, cold reduced 50%, and annealed: 260°C (500°F) for 30 min. did not visibly alter the cold worked FCC grains (note slip lines) and annealing twins; 371°C (700°F) for 30 min. produced partial recrystallization. Tint etched with Klemm's I reagent (Originals at 100X, crossed polarized light plus sensitive tint).

Cu–30% Zn, HE, CR 50%, Annealed 800 ° F/427 °C



Left: 4 minutes Right: 8 minutes

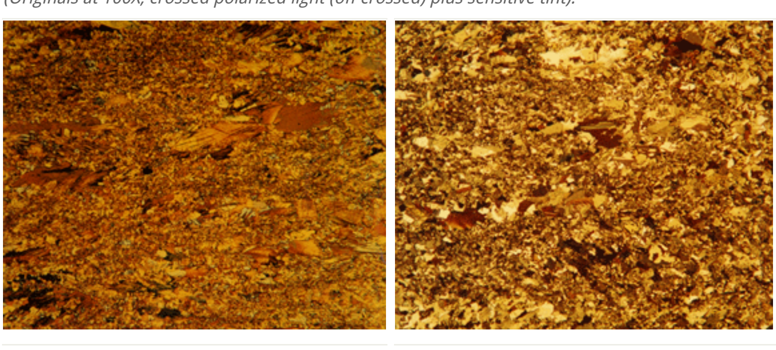
Figures 6 and b: Microstructure of wrought cartridge brass, Cu – 30% Zn, cold reduced 50%, annealed at 427°C (800°F): 4 minutes did not visibly affect the cold worked grain structure (note heavy slip lines); 8 minutes has produced the start of recrystallization. Tint etched with Klemm's I (Originals at 100X, crossed polarized light (off crossed) plus sensitive tint).



Left: 15 minutes Right: 30 minutes

Figures 6c and d: 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)).

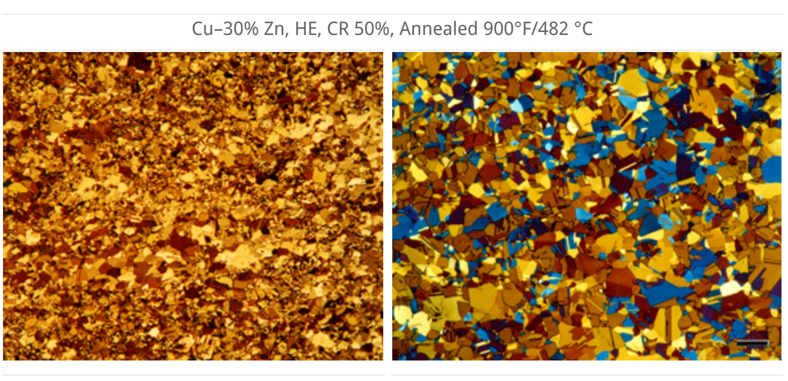
Cu–30% Zn, HE, CR 50%, Annealed 900°F/482 °C



Left: 15 minutes, Off XP, Original 100X Right: 60 minutes, XP+ST, 100X

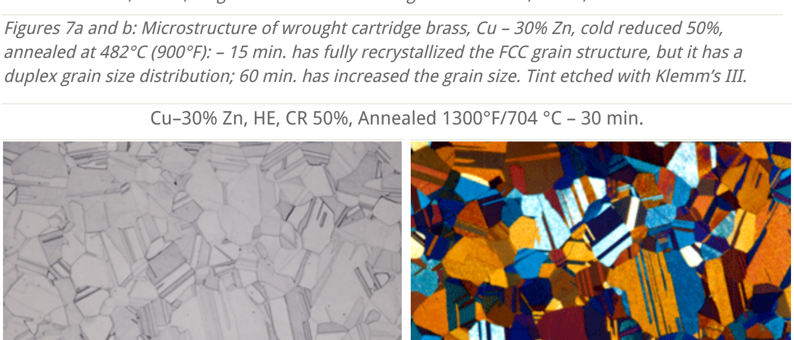
Figures 7a and b: Microstructure of wrought cartridge brass, Cu – 30% Zn, cold reduced 50%, annealed at 482°C (900°F): – 15 min. has fully recrystallized the FCC grain structure, but it has a duplex grain size distribution; 60 min. has increased the grain size. Tint etched with Klemm's III.

Cu–30% Zn, HE, CR 50%, Annealed 1300°F/704 °C – 30 min.



Left: NH_4OH – H_2O_2 Right: Klemm's I, XP+ST, Original at 50X

Figure 8a and b: 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.



Left: Klemm's III, Original at 50X Right: Beraha's PbS, Original at 50X

Figures 8c and d: 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.

George Vander Voort has a background in physical, process and mechanical metallurgy and has been performing metallographic studies for 47 years. He is a long-time member of ASTM Committee E-4 on metallography and has published extensively in metallography and failure analysis. He regularly teaches MEI courses for ASM International and is now doing webinars. He is a consultant for Struers Inc. and will be teaching courses soon for them. He can be reached at 1-847-623-7648, EMAIL: georgevandervoort@yahoo.com and through his web site: **www.georgevandervoort.com**

To View a listing of all George's articles please click here

Read George Vander Voort's Biography

© Copyright 2016 VAC AERO - All rights reserved.