

# An unusual microstructure in $\alpha$ - $\beta$ brass

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## Abstract

An early 19th-century brass part displayed a widmanstätten structure of very fine, parallel rods or needles of  $\alpha$ -phase brass precipitated in a matrix of  $\beta$ -phase brass that had been retained by quenching. An annealing temperature of about 800°C and a fast quench of only a few seconds were estimated from the microstructure.

An interesting microstructure was observed in the course of a metallographic examination of a brass part original to an 1810 fortepiano. The part was made of rod 7/64" (2.78mm) in diameter, which was sectioned for study both longitudinally and transversely. EDS standardless analysis of the prepared surfaces estimated a high-zinc brass of about 65% copper and 35% zinc, a composition known commercially as yellow brass. No other elements were detected, nor did the microstructure (Fig 1) reveal any inclusions, only grains of  $\alpha$  phase in a grain boundary network of  $\beta$  phase. The two phases differ in composition and also in crystallographic structure,  $\alpha$  brass being face-centered cubic and  $\beta$  body-centred cubic.

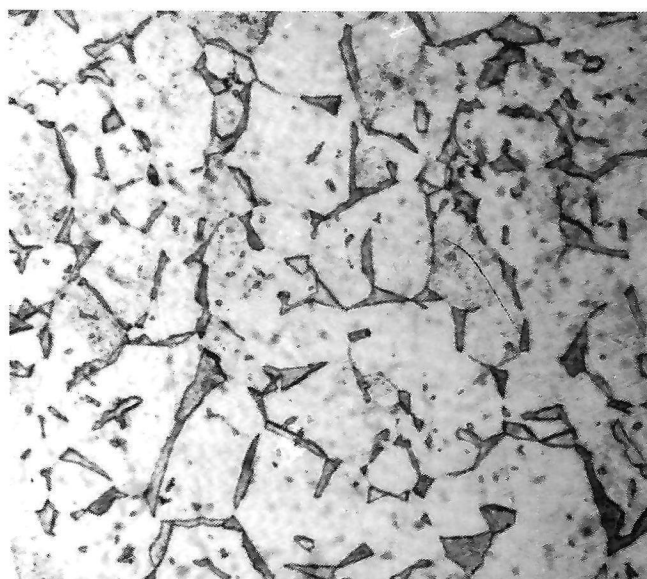


Fig 1: Longitudinal section of 1810 brass rod, showing retained- $\beta$  phase at the boundaries of the recrystallised  $\alpha$ -phase grains ( $\times 650$ ).

## Annealing temperature

Complete annealing of the original drawn structure of the rod was evident from the grains of the  $\alpha$  phase, which were equiaxed; the grain size was the same in both the longitudinal and the cross section. Estimated from the section in Figure 1 the diameter ranged generally between 0.02 and 0.04mm. Since grain size increases with the temperature of annealing but less so with its duration, the measured grain size could only fix the limits of the annealing treatment, between 500°C for two hours and a minute or two at 800°C.<sup>1</sup>

A high annealing temperature was attested by the apparent lack of annealing twins, the lack of dezincification and the presence of a retained  $\beta$  phase. The brass had been heavily worked when formed into rod; had the metal been annealed at the lower temperatures usual for brass, annealing twins would have been abundantly present.<sup>2</sup> The annealing time was too brief to result in visible evidence of loss of zinc to the atmosphere; any dezincification would have increased the area of the  $\alpha$  phase relative to that of the  $\beta$  phase in the structure near the surface.<sup>3</sup> Complete annealing to large, equiaxed grains occurring in a relatively brief time was evidence of a high annealing temperature.

The recommended annealing range for yellow brass is between 425-700°C,<sup>4</sup> well within the limits of the  $\alpha$  phase. Heating to a higher temperature was needed to produce the  $\beta$  phase at the  $\alpha$ -phase grain boundaries, and quenching to retain it. If cooled slowly, the  $\beta$  phase present at high temperatures in brasses of up to about 39% zinc will transform entirely to the  $\alpha$  phase and result in a single-phase structure (see the equilibrium phase diagram, Fig 2). The amount of  $\beta$  phase retained by quenching is another, and more precise, indicator of the temperature from which the brass was quenched. Since the grain structure of the rod was equiaxed the proportion of  $\beta$  could be measured from the relative area of  $\beta$  visible in either section.<sup>5</sup> In Figure 1 the proportion was 10% (815 out of 7800 squares measured), corresponding to an effective quench from about 800°C.

The Diamond Pyramid Hardness (DPH) of the rod was measured on the longitudinal section using the customary 100-gram load. The hardness was only 90 kg/mm<sup>2</sup>, quite

soft, as would be expected of a thoroughly annealed brass.

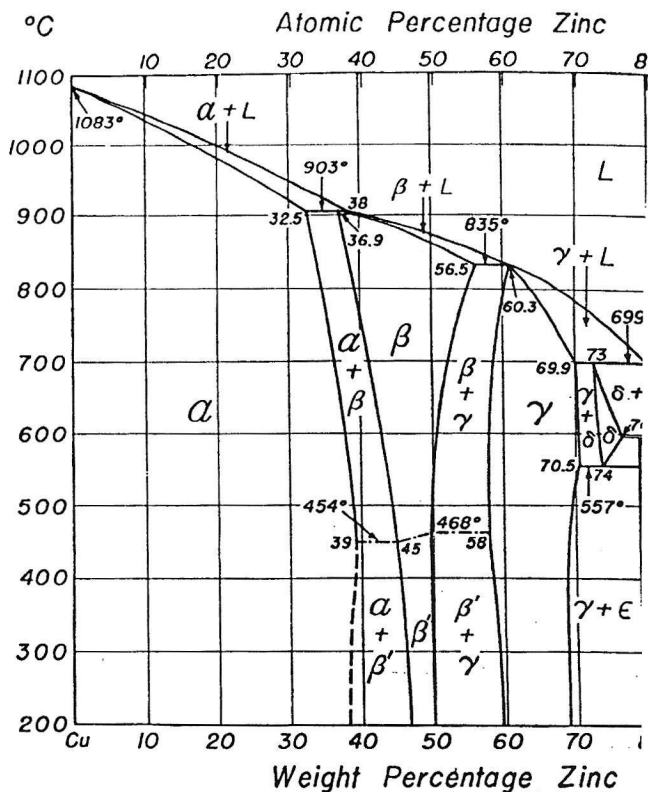


Fig 2: Copper-zinc equilibrium phase diagram. Composition is in weight percent. The brass in Figure 1 contained about 35% zinc.

An annealing temperature as high as 800°C is not usual practice. That this fortepiano maker may have annealed brass at such high temperatures routinely was suggested by the appearance of the adjoining piece of brass in the assembly (Figure 3). The part was fabricated from thin brass sheet bent to 90 degrees; where the sheet was bent there is a visible roughness or texture in the surface that is described in industrial practice as 'orange peel'. The texture results from forming metal with the excessively large grain size that results from over-annealing. In cartridge brass (30% zinc) this grain size must be greater than 0.01mm; a smaller grain size would maintain a smooth surface.<sup>6</sup>

#### Widmanstätten structure

The  $\beta$ -phase network in the rod presented an unusual structure when examined at higher powers in a scanning electron microscope (Fig 4, at  $\times 8,000$ ). This microstructure was not to be found in the standard texts and atlases of metal microstructures consulted. In ordinary metallographic experience it most resembles pearlite in steel but instead of lamellae the excess copper in solution in the  $\beta$  phase precipitated out in the form of

very fine rods of  $\alpha$  brass. These seemed to correspond to the 'needles' referred to by Phillips and Brick.<sup>7</sup>

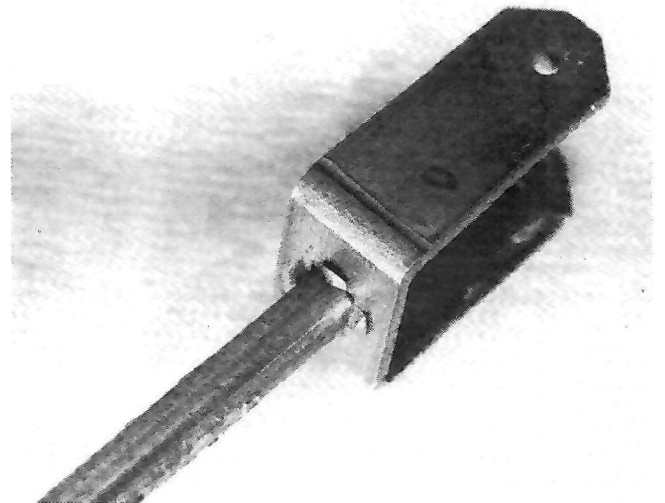


Fig 3: Brass kapsel from a 1810 fortepiano. The rod ('stem') and the bent sheet ('yoke') were joined mechanically after each was separately heat-treated and formed.

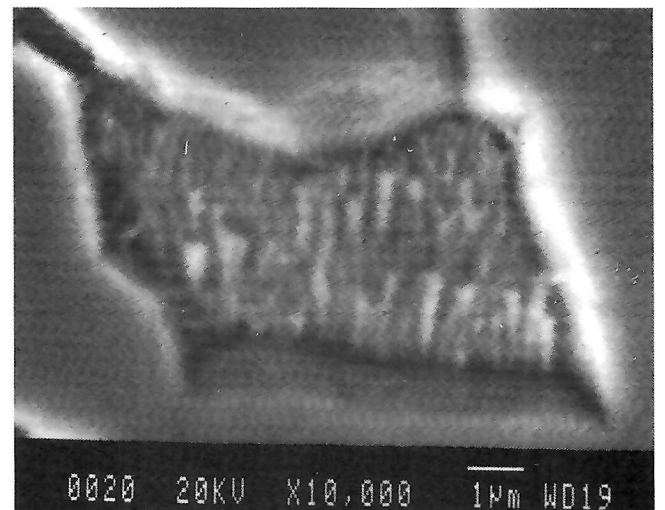


Fig 4: Scanning electron micrograph of the widmanstätten structure of  $\alpha$ - $\beta$  brass (parallel rods) precipitated out of the  $\beta$  phase (NB: mag =  $\times 8000$ ).

Frederick N Rhines, in mimeographed class notes prepared for his students at Carnegie Institute of Technology (now Carnegie-Mellon University) in Pittsburgh in 1948, sketched a similar  $\alpha$ - $\beta$  brass structure as an illustration of microstructures possible in a peritectic alloy. Rhines described the second phase in a 65.5Cu/34.5 brass quenched from 880°C as  $\beta$  (sic) 'precipitated in a massive Widmanstätten pattern'.<sup>8</sup>

Although recognised in the coarse structure of iron meteorites by Aloys von Widmanstätten as early as 1808,<sup>9</sup> at present a widmanstätten morphology is defined

as one where plates or rods precipitate along specific crystallographic orientations of the parent matrix. In the case of  $\alpha$ -brass precipitates the preferred direction is along the [111] direction in the  $\beta$ -phase crystals, thus the close alignment of the rods that is visible in Figure 4.

Chadwick recently reviewed the solid-state transformations occurring in brass<sup>10</sup> and noted that the time-temperature-transformation (TTT) curve established by Flewitt and Towner for 59.5/40.5 brass<sup>11</sup> indicates that widmanstätten rods are produced in brass quenched from temperatures of 500°C and above in about one second, a result consistent with the interpretation above. Most likely water was used to quench the brass rod. With its small mass a very rapid quench rate would have resulted.

### Conclusion

The microstructure discussed here is rarely observed in modern brass. However in the study of earlier industrial practice, especially before the close control of high temperature became possible with the invention of the thermocouple by Le Chatelier in 1887,<sup>12</sup> evidence from structures such as this may prove useful in gauging the degree of control actually obtained.

### Acknowledgments

The author is grateful to Rod J Regier for the sample of brass rod and to the late B Floyd Brown for the gift of Professor Rhine's notes. This study is dedicated to the late Professor Cyril Stanley Smith in memory of many helpful discussions of the behaviour of copper alloys and their microstructures.

### References

1. Taylor L (ed), *Metals Handbook* (Cleveland, Ohio, 1948), 879, Figure 4.
2. For comparison see micrographs in *Metals Handbook Eighth Edition*, Volume 7: Atlas of Microstructures of Industrial Alloys (Metals Park, Ohio 1972), especially p.286, Figs 2363-2365.
3. Sykes C and Wilkinson H, 'The transformation in the  $\beta$  brasses', *Journal of the Institute of Metals* 61 (1937) 223-240. Figure 2 shows dezincification in a 50/50 brass that produced traces of  $\alpha$  phase in the otherwise completely  $\beta$ -phase microstructure.
4. Taylor 1948 (note 1), 917.
5. This assumes that the densities of both phases are similar.
6. *Metals Handbook Eighth Edition*, Volume 7, (Metals Park, Ohio 1972), 282, Figs 2323 and 2327.
7. Phillips A and Brick R M, 'Cu-Zn Copper-Zinc', in Taylor 1948 (note 1), 1206.
8. Frederick N Rhines, *Non-Ferrous Metallography Notes, Part II, Copper and the White Metals*, Chapters 20-37 inclusive, revised, Pittsburgh 1953: a set of mimeographed notes prepared for students at the Carnegie Institute of Technology. A copy of these notes is available in the Museum Support Center Library of the Smithsonian Institution under the call number TN93. C9R47 1953. In Rhines' sketch on page 22-d the amount of  $\beta$  would have been nearer 50% had the quench been applied before his specimen began losing temperature; the specimen was more likely close to 840°C when the quench took effect. An annealing temperature of 880°C is very close to the peritectic temperature, 903°C, where the metal begins to liquify and becomes 'burnt'.
9. Mehl R F, 'On the Widmanstätten structure', in C S Smith (ed), *The Sorby Centennial Symposium on the History of Metallurgy* (New York 1965), 245-269. Smith C S, *A History of Metallography: The development of ideas on the structure of metals before 1890* (Cambridge USA and London 1988), 150-155.
10. Chadwick G A, *Metallography of Phase Transformations* (New York 1972), 226-228, Figs 7.4(c) and 7.5(b).
11. Flewitt P E J and Towner J M, 'The decomposition of beta prime in copper-zinc alloys', *Journal of the Institute of Metals* 95 (1967), 273.
12. Barclay W R, 'Contributions of metallurgy to engineering progress', *Mining and Metallurgy* 19 (1938), 397-400.

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