

Appendix 1: Colour photomicrographs to text



a. Face



b. Side

Figure. 2.1 The wooden pattern used in the experiment

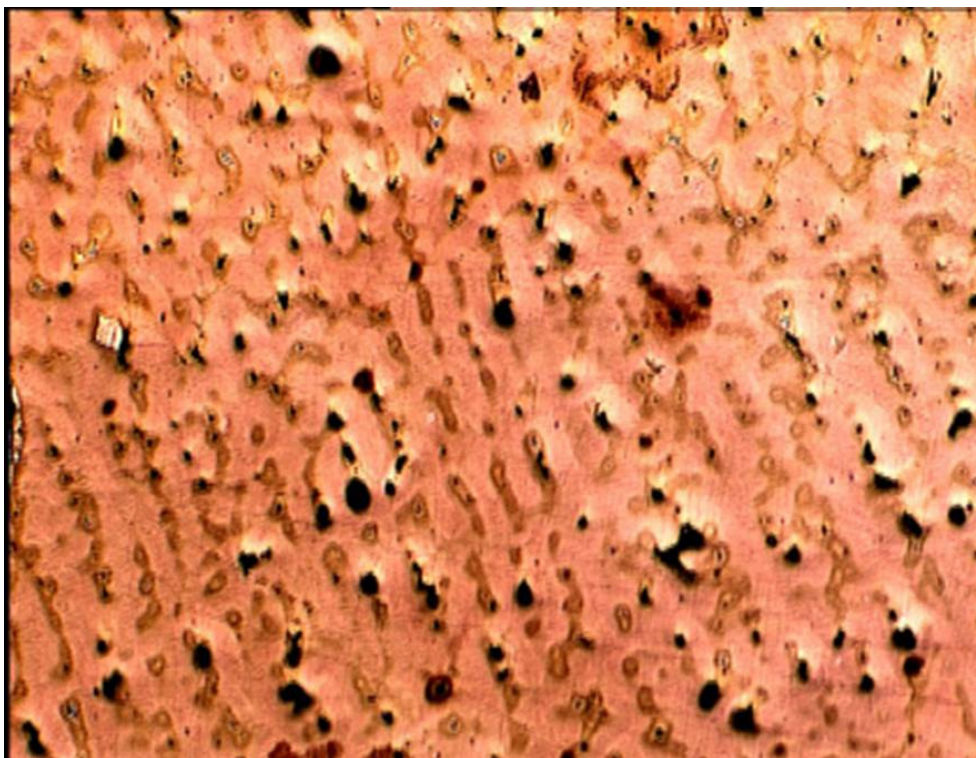


Figure 2.2 Photomicrograph of cast object No26, showing extensive porosity:
6% Sn bronze, air-cooled (image width 1.3 mm)

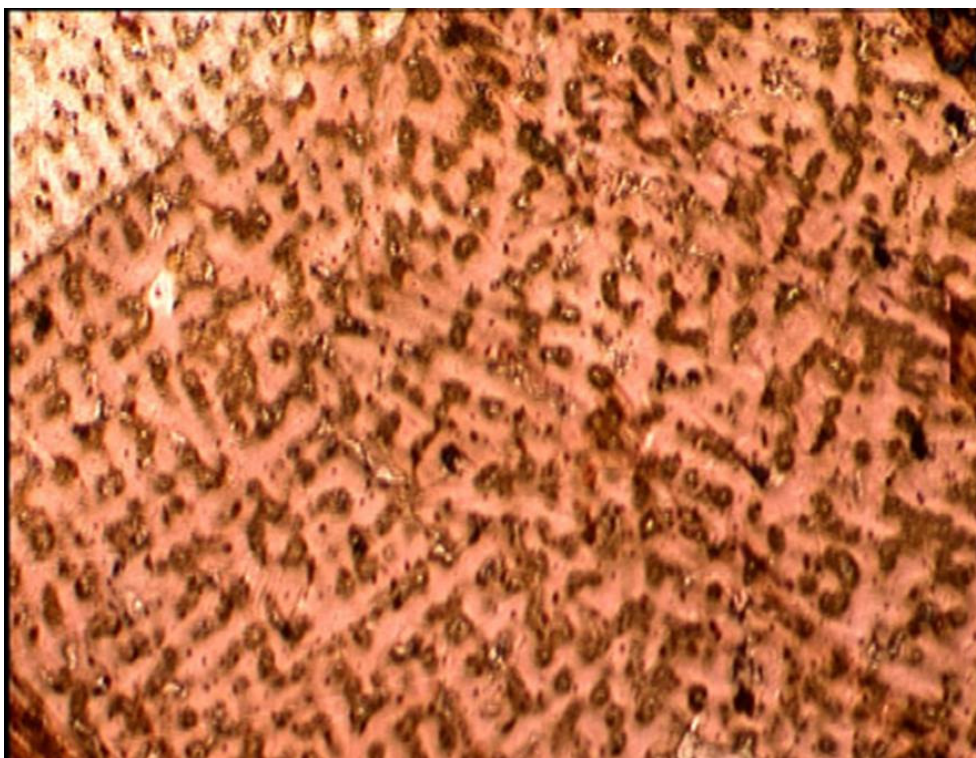


Figure 2.3 Photomicrograph of 6% Sn bronze, air-cooled, showing little porosity
(image width 1.3mm)



Figure 2.4 The charge in the crucible covered with charcoal



Figure 2.5 A lid covered the crucible during



Figure 2.6 Temperature of the melts measured with a thermocouple



Figure 2.7 Charcoal residue skimmed off before pouring

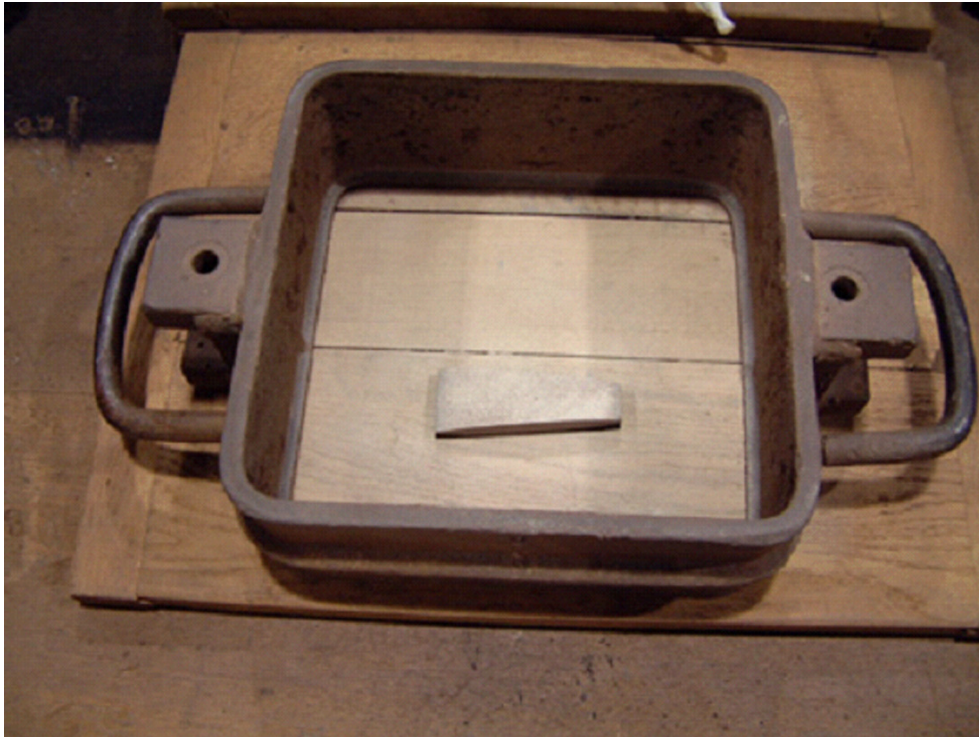


Figure 3.1 The pattern placed in the drag box



Figure 3.2 The cope box placed on the drag box for completion of the mould



Figure 3.3 both drag and cope box filled with sand, three holes made and feeder removed



Figure 3.4 Mould opened after cooling, showing position of the nine vents

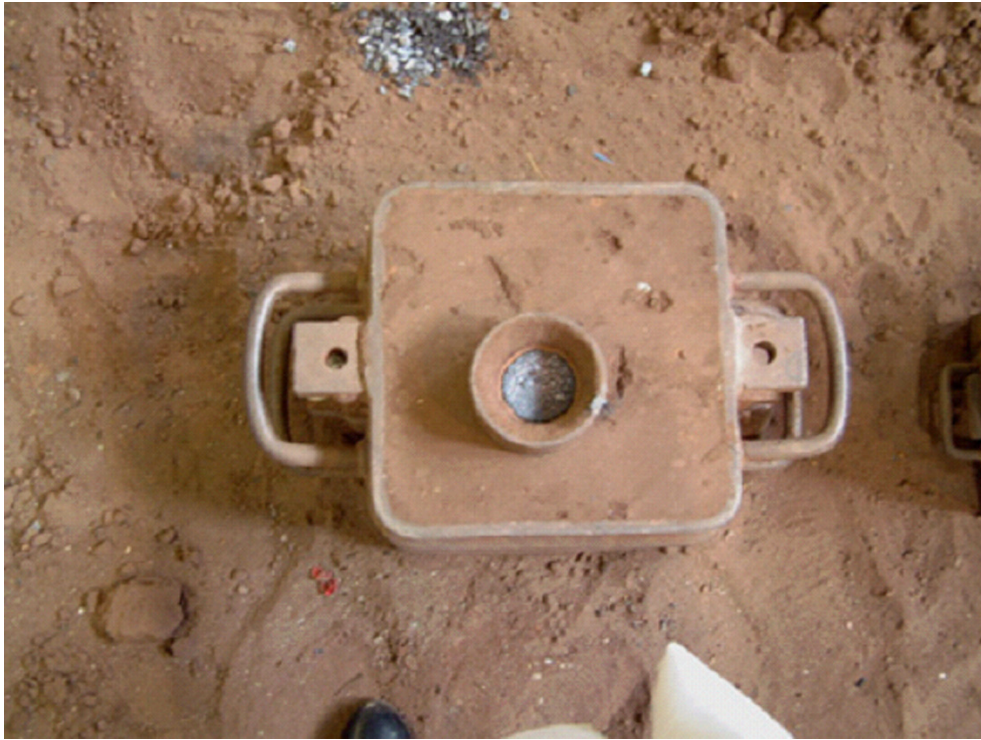


Figure 3.5 Metal filled up to the runner bush

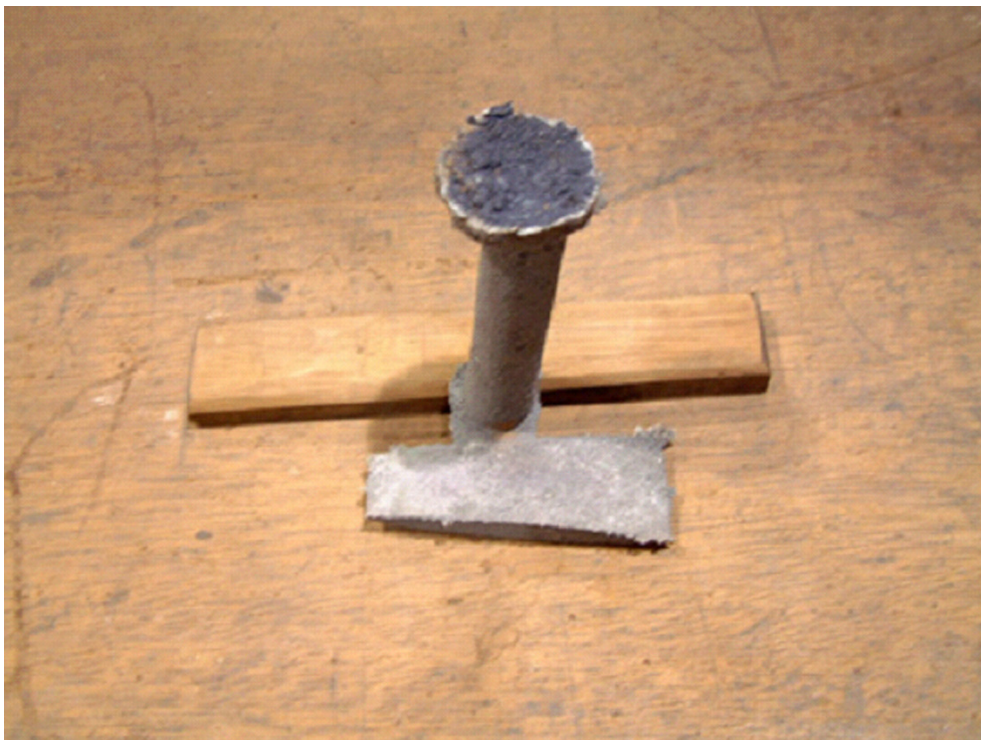


Figure 3.6 A cast axe with the feeder still attached

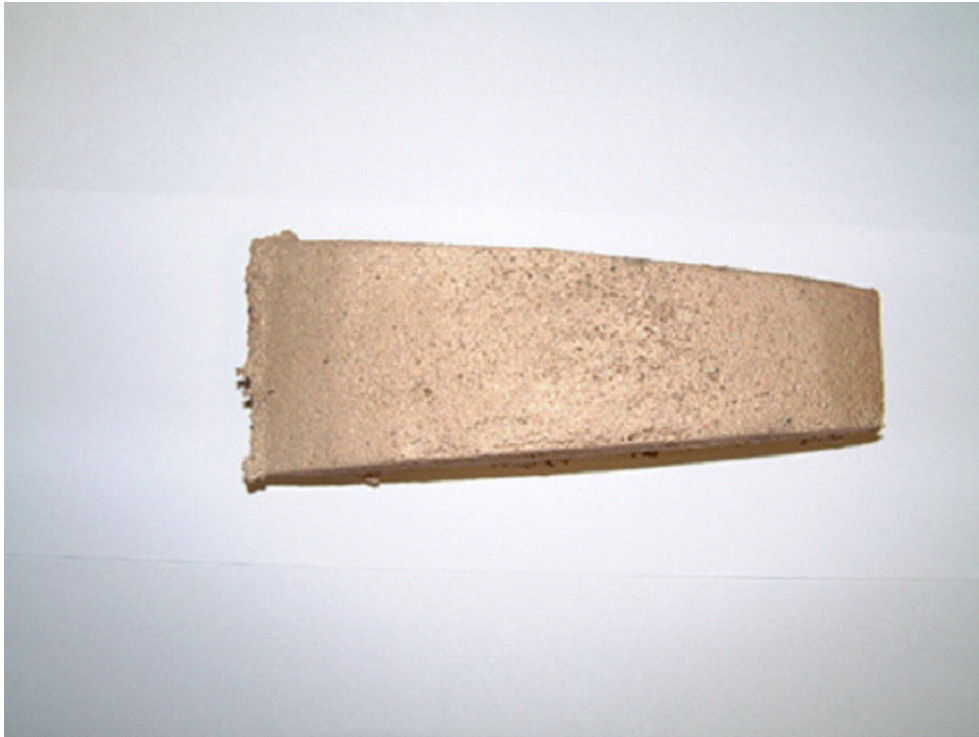


Figure 3.7 A finished axe after feeder removed and sand blasted

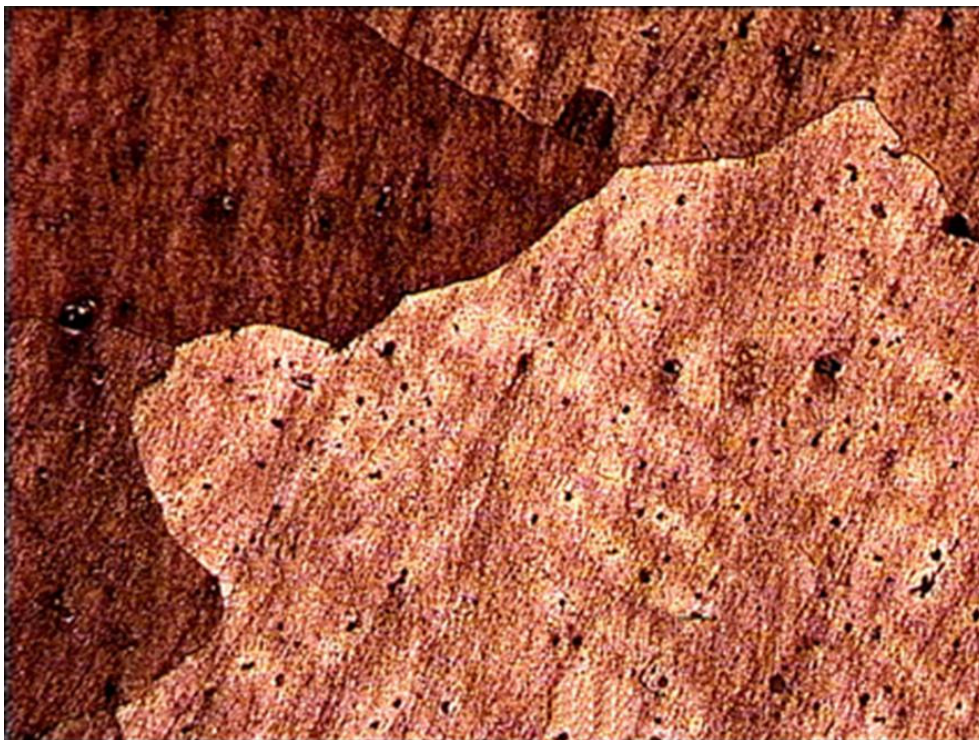


Figure 3.8 Photomicrograph of 2% Sn bronze; water-quenched, showing a granular structure with coring.
Image width 0.65mm



Figure 3.9 Photomicrographs of 2% Sn; air-cooled, showing a granular structure without obvious coring very few islands. Image width 0.65mm.



Figure 3.10 Photomicrograph of 2% Sn + 6%Pb; air-cooled, showing a granular structure and pores on the grain boundaries. Image width 1.3mm.

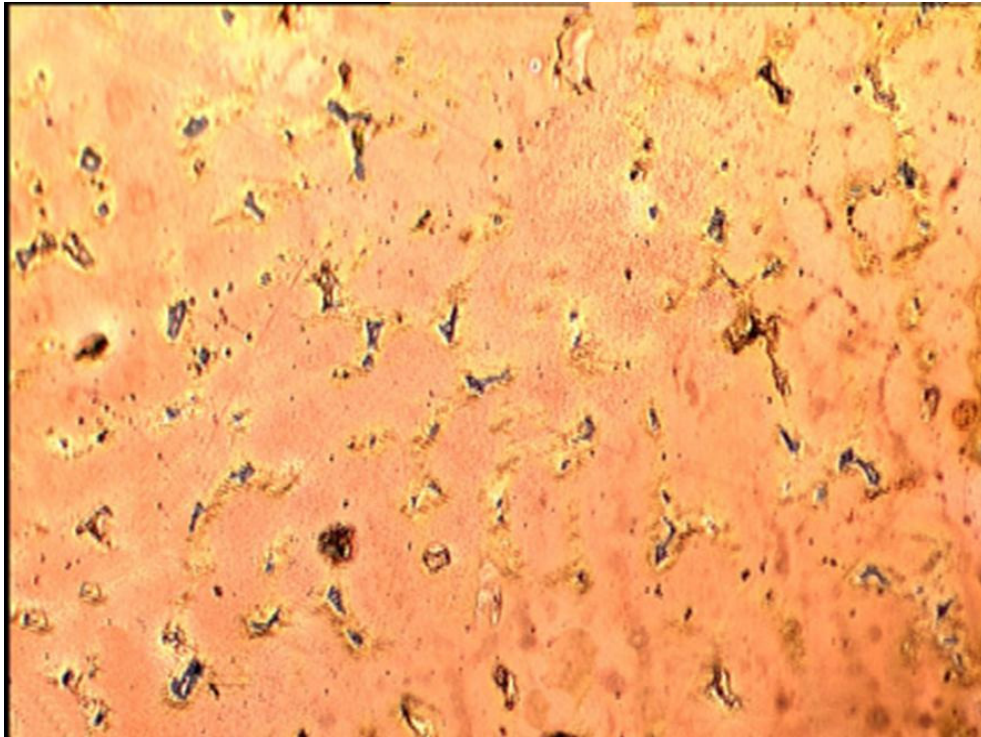


Figure 3.11 Photomicrograph of 6% Sn bronze; water-quenched, showing a dendritic structure with $\alpha+\delta$ eutectoids. Image width 0.65mm.

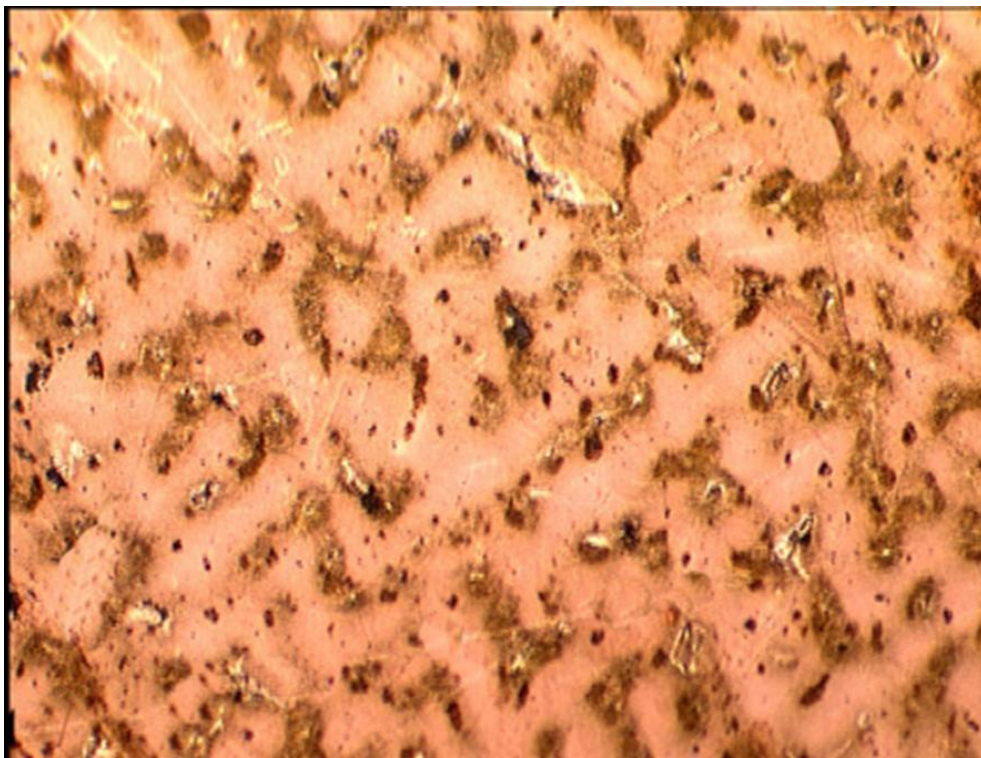


Figure 3.12 Photomicrograph of 6% Sn bronze; air-cooled, showing a dendritic structure with very few $\alpha+\delta$ eutectoids. Image width 0.65mm.



Figure 3.13 Photomicrograph of 10% Sn bronze; water-quenched, showing a darker $\alpha+\delta$ eutectoids. Image width 0.13mm.



Figure 3.14 Photomicrograph of 10% Sn bronze; air-cooled, showing islands of $\alpha+\delta$ eutectoids. Image width 0.13mm.

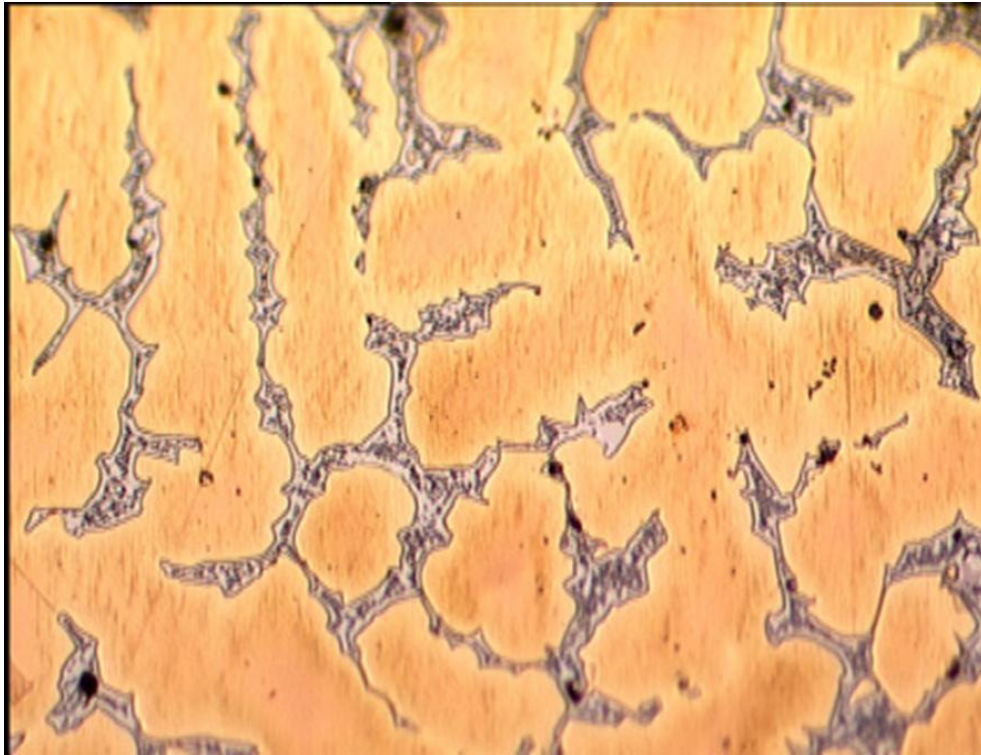


Figure 3.15 Photomicrograph of 15% Sn bronze; air-cooled, showing massive $\alpha+\delta$ eutectoids in the interdendritic regions. Image width 0.33mm.

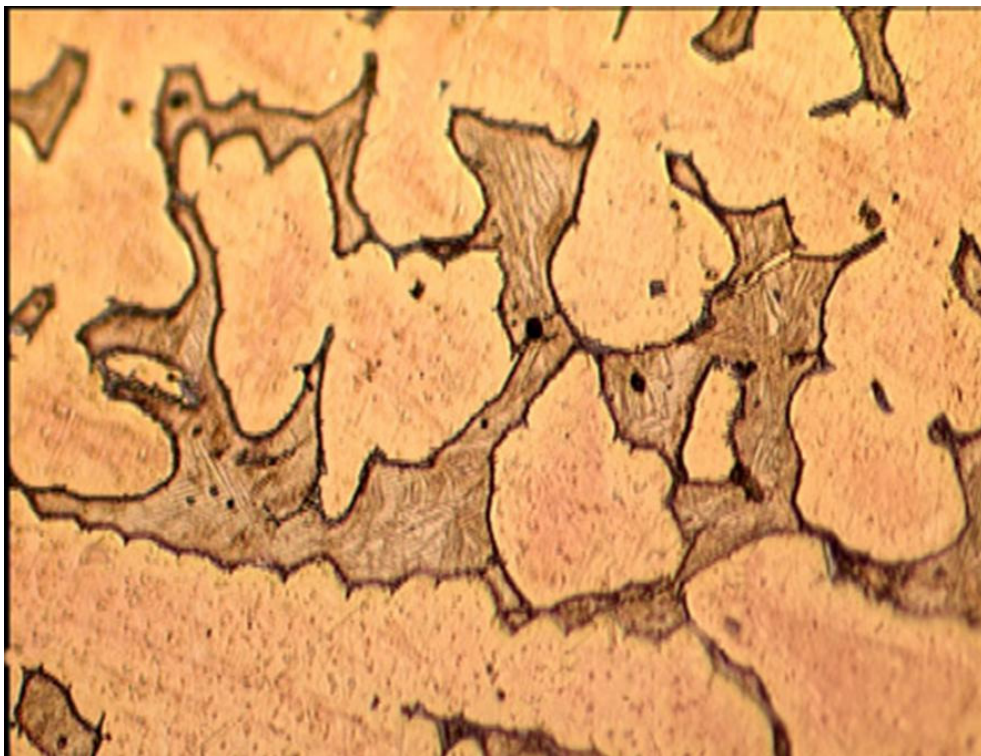


Figure 3.16 Photomicrograph of 15% Sn bronze; water-quenched, showing needle β in the interdendritic regions. The dark phase surrounding the needle β is likely to be δ phase. Image width 0.33mm.

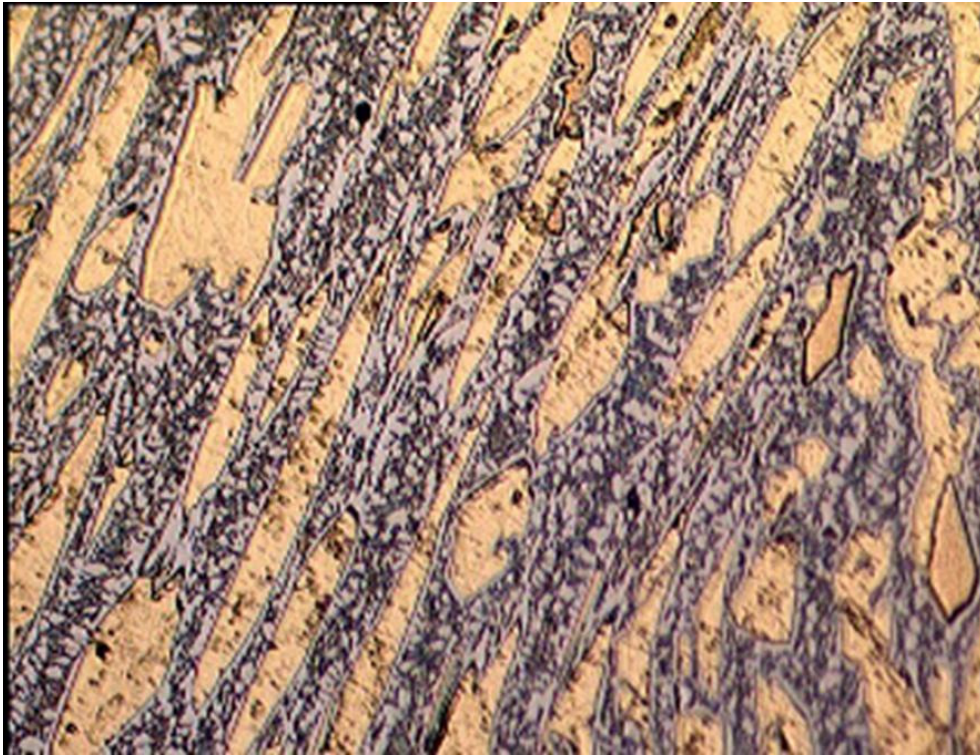


Figure 3.17 Photomicrograph of 23% Sn bronze; air-cooled, showing massive $\alpha+\delta$ eutectoids. Image width 0.33mm.



Figure 3.18 Photomicrograph of 23% Sn bronze; water-quenched, showing dark grain boundaries and needle β within the grains. Image width 1.3mm.

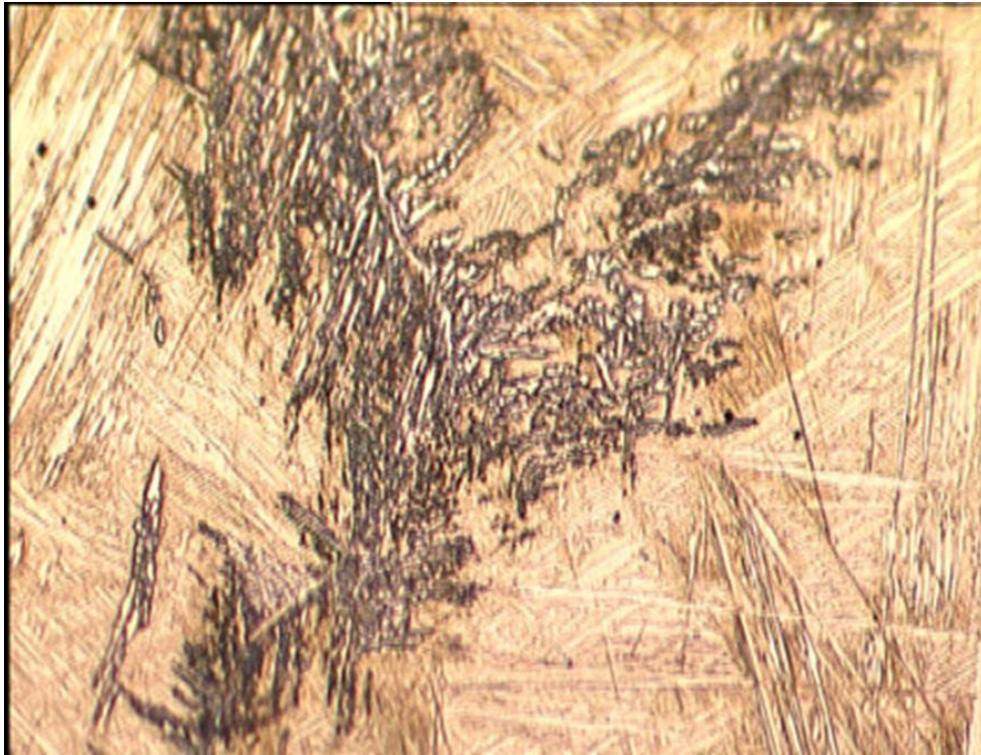


Figure 3.19 Photomicrograph of the same sample as in figure 3.18 at higher magnification. The dark phase on the boundaries is likely to be δ phase. Image width 0.33mm.

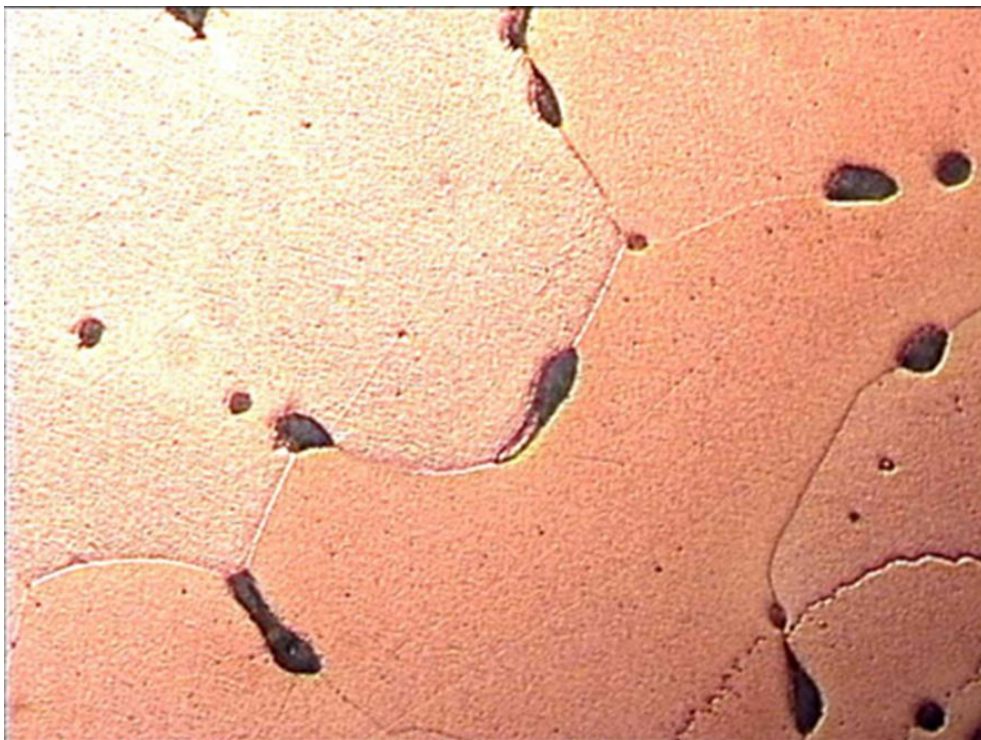


Figure 3.21 Photomicrograph of 2%Sn bronze+ 2%Pb; water-quenched, showing lead droplets on the grain boundaries. Image width 0.13mm.

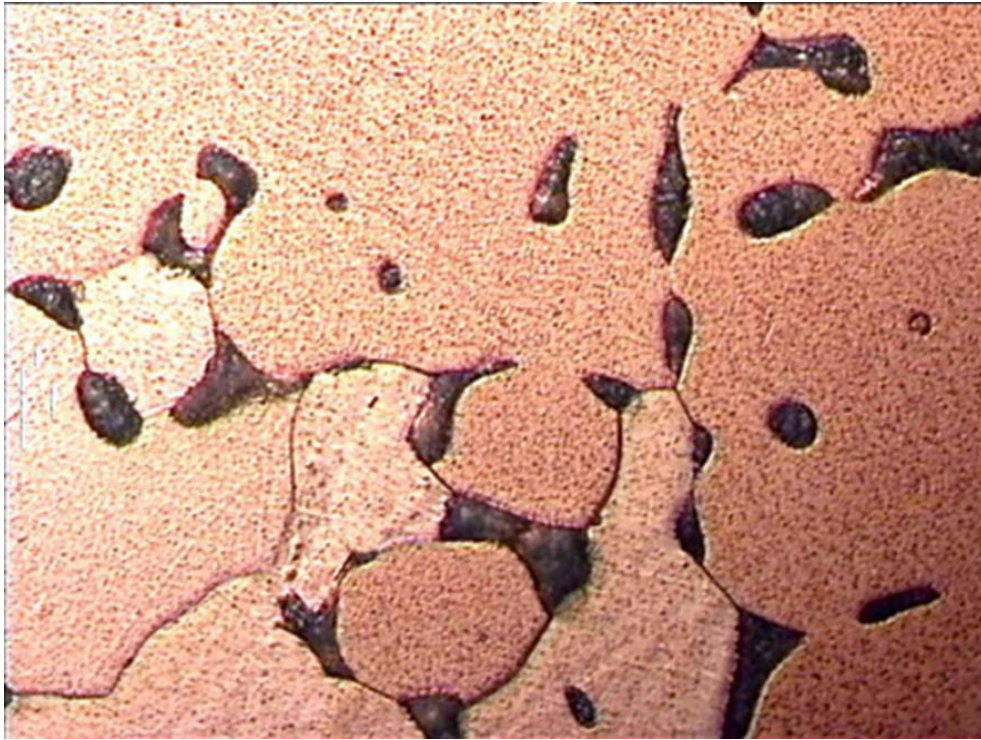


Figure 3.22 Photomicrograph of 2%Sn bronze+ 10%Pb; water-quenched, showing lead droplets both on the grain boundaries and within the grains. Image width 0.13mm.



Figure 4.1 The pattern and frame used to prepare the mould



Figure 4.2 The completed first half of the mould with sawdust spread on

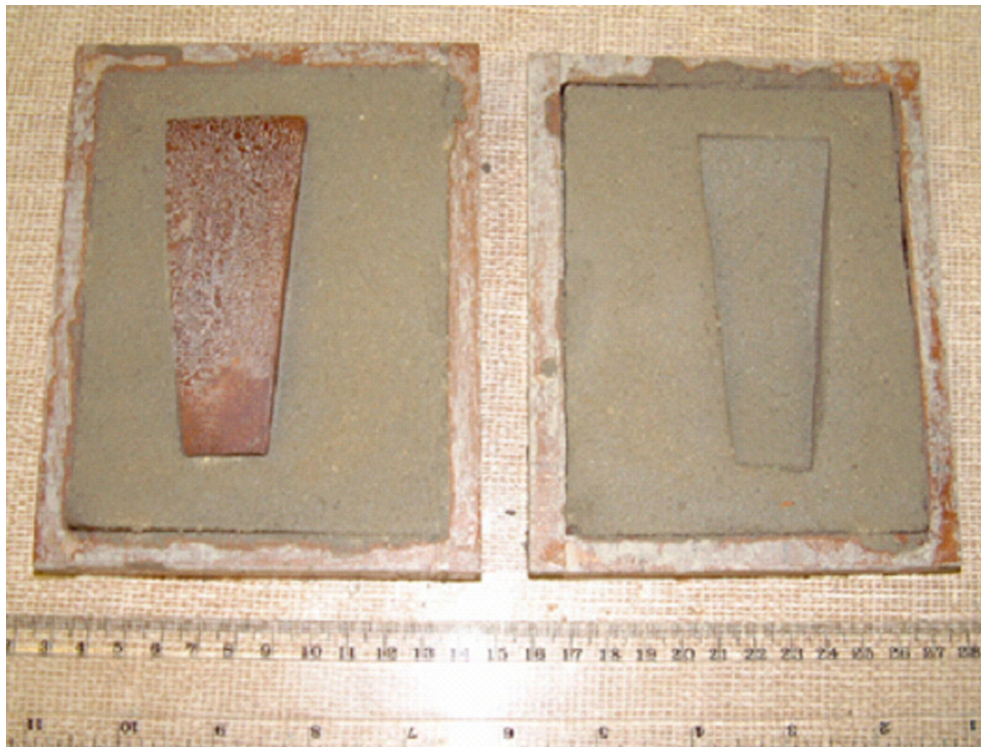


Figure 4.3 The two halves of the mould separated



Figure 4.4 Two completed parts of the mould, showing small holes and runner inlet



Figure 4.5. A completed mould assemblage



Figure 4.6 Dried moulds (two bottom rows) and fired moulds (top row)



Figure 4.7. Extensive flashing occurred during an initial casting experiment



Figure 4.8. Pouring molten metal into a clay mould, weighed down by heavy metal pieces to prevent excessive flashing



Figure 4.9. Sand blasted axe (6%Sn+10%Pb) cast in clay mould, showing smooth surface



Figure 4.10. Untreated axe (23%Sn) cast in clay mould, showing shrinkage on the surface

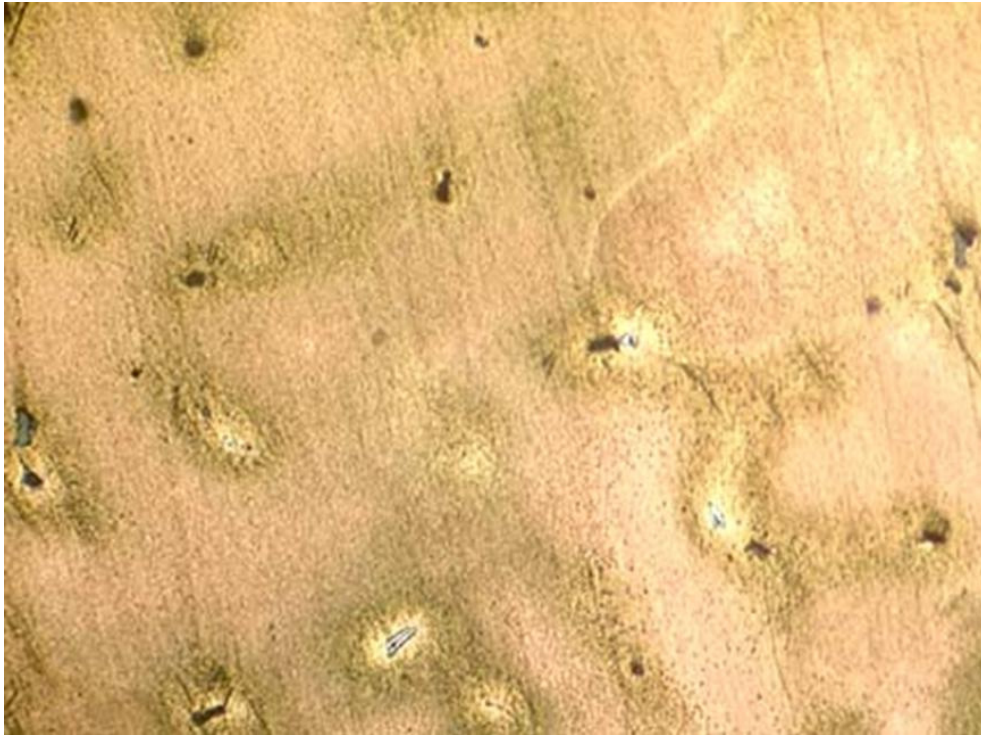


Figure 4.11. 6% Sn bronze cast in a preheated (350°C) mould and air-cooled, showing a few islands of eutectoid ($\alpha+\delta$). Image width 0.33mm

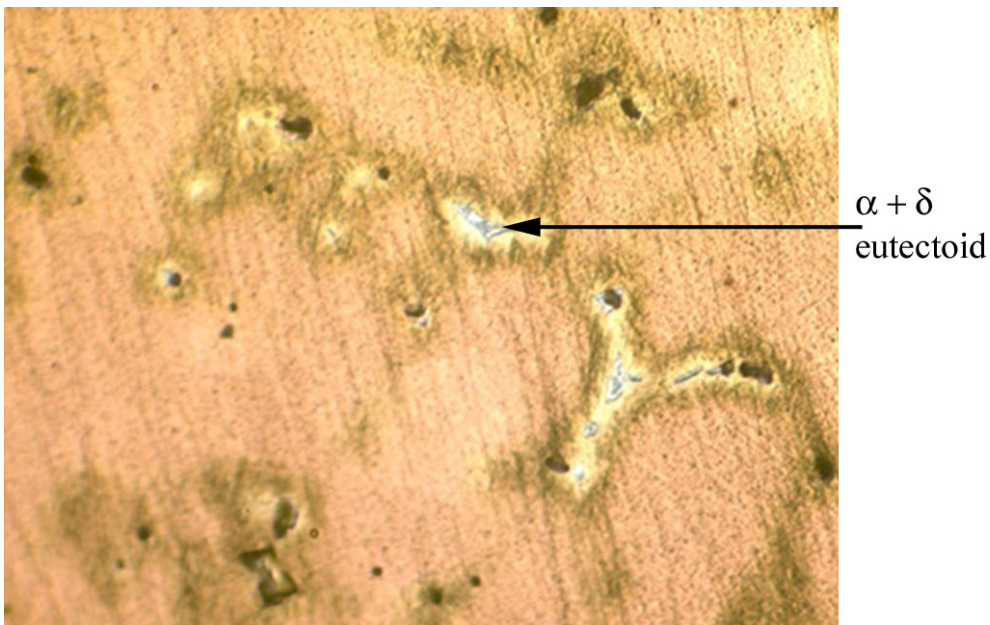


Figure 4.12. 6% Sn bronze cast in an unpreheated mould and air-cooled, showing presence of eutectoid ($\alpha+\delta$). Image width 0.33mm

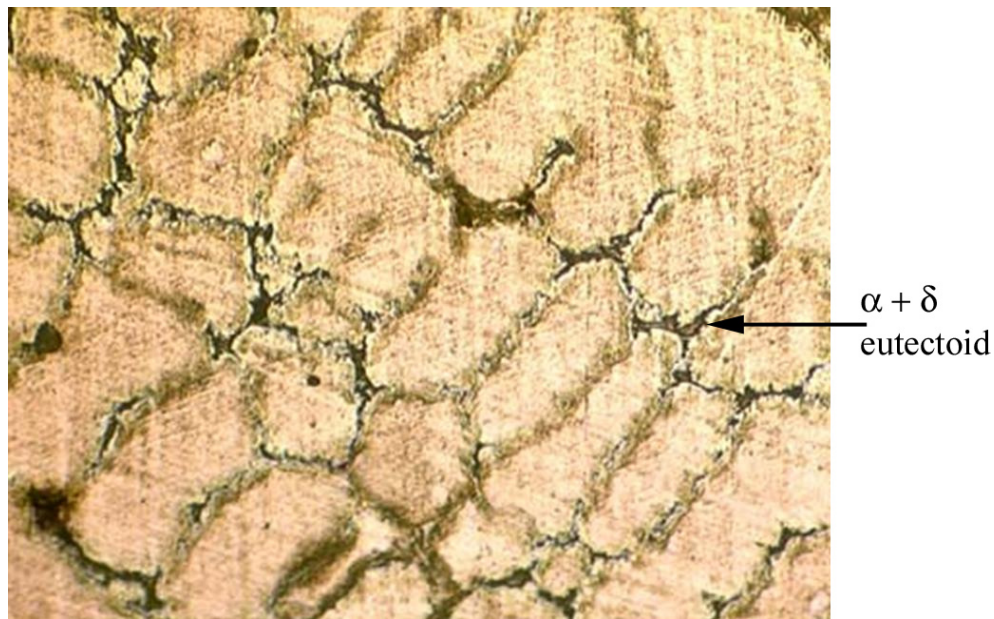


Figure 4.13. 6% Sn bronze cast in an unpreheated mould and water-quenched, showing eutectoid ($\alpha + \delta$) on grain boundaries, where the δ phase is darker than usual. Image width 0.33mm



Figure 4.14. 2% Sn bronze cast in an unpreheated mould and air-cooled, showing a granular structure. Image width 1.3 mm

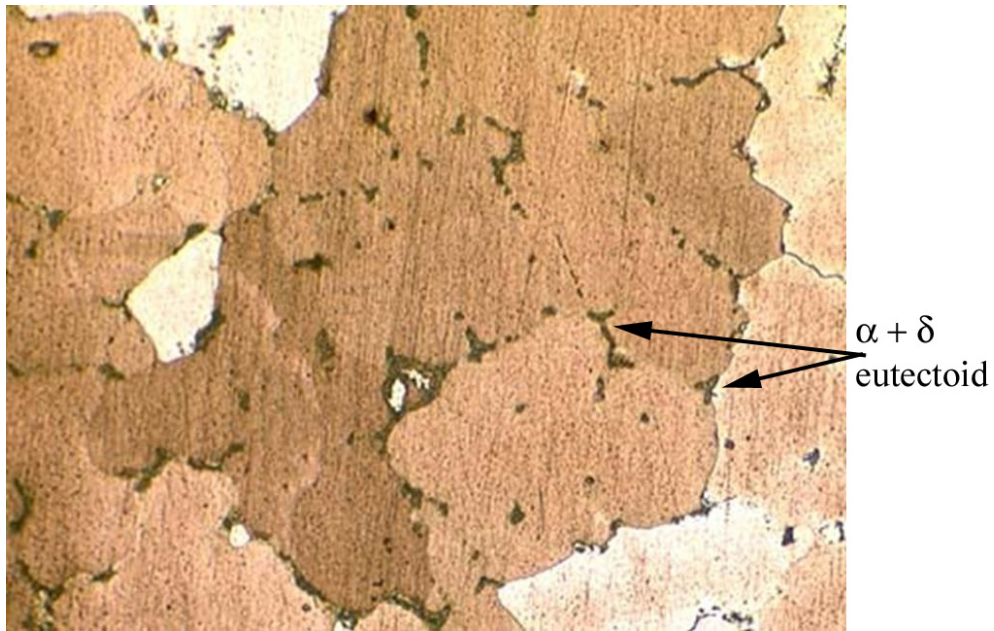


Figure 4.15. 2% Sn bronze cast in an unpreheated mould and water-quenched, showing eutectoid of ($\alpha + \delta$) on grain boundaries. Image width 0.65mm

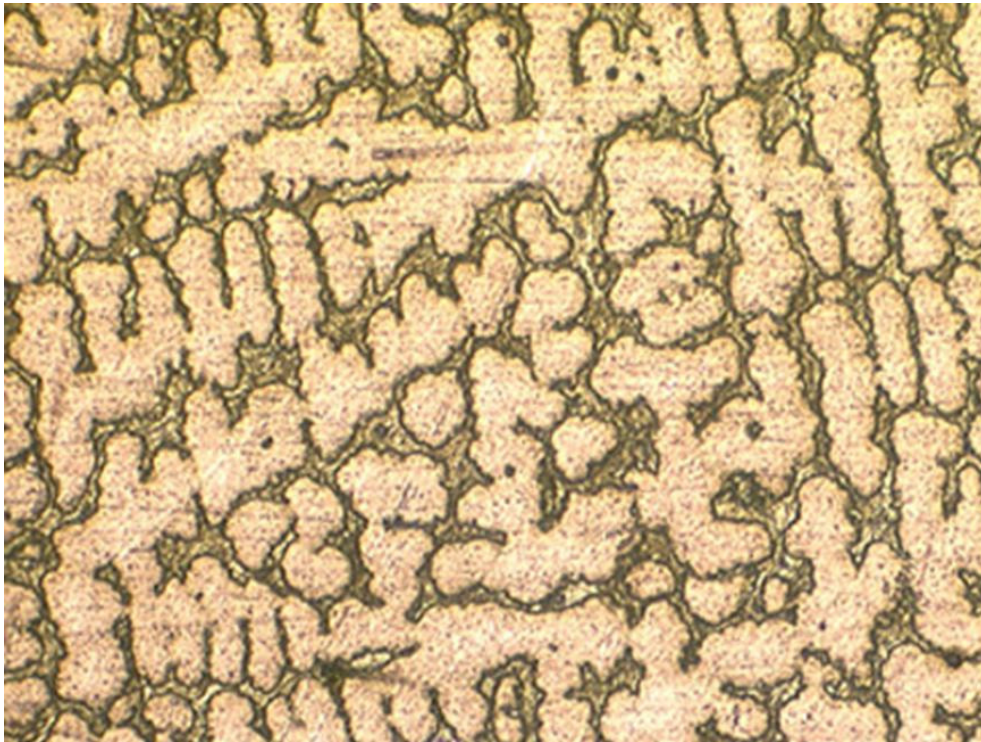


Figure 4.16. 10% Sn bronze cast in an unpreheated mould and water-quenched, showing pronounced dendritic structure and massive eutectoid ($\alpha + \delta$). Image width 0.65mm

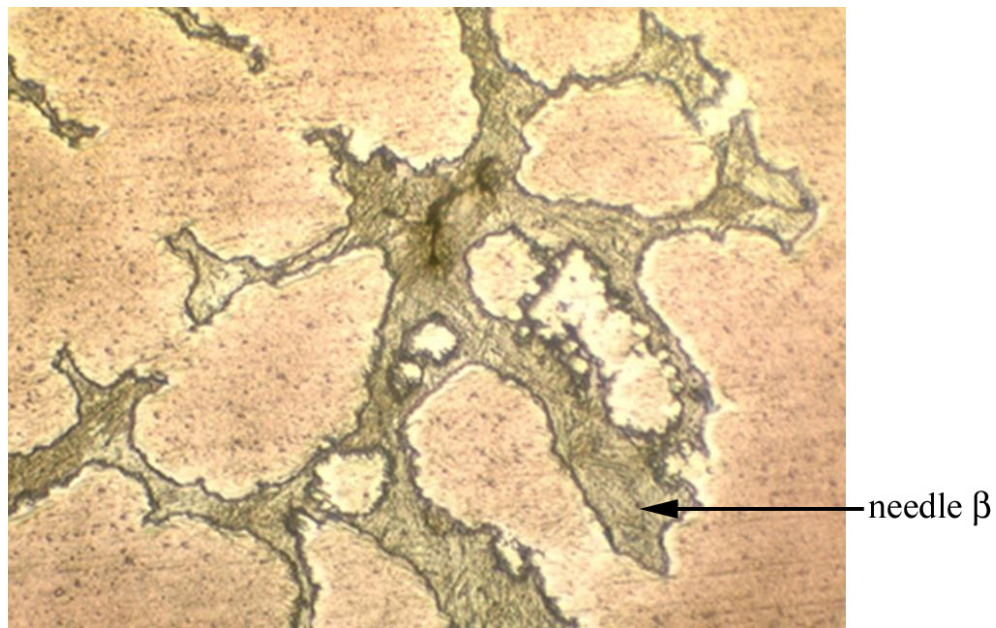


Figure 4.17. Same sample as Fig. 4.16 at higher magnification, showing interdentritic needle β phase. Image width 0.16mm

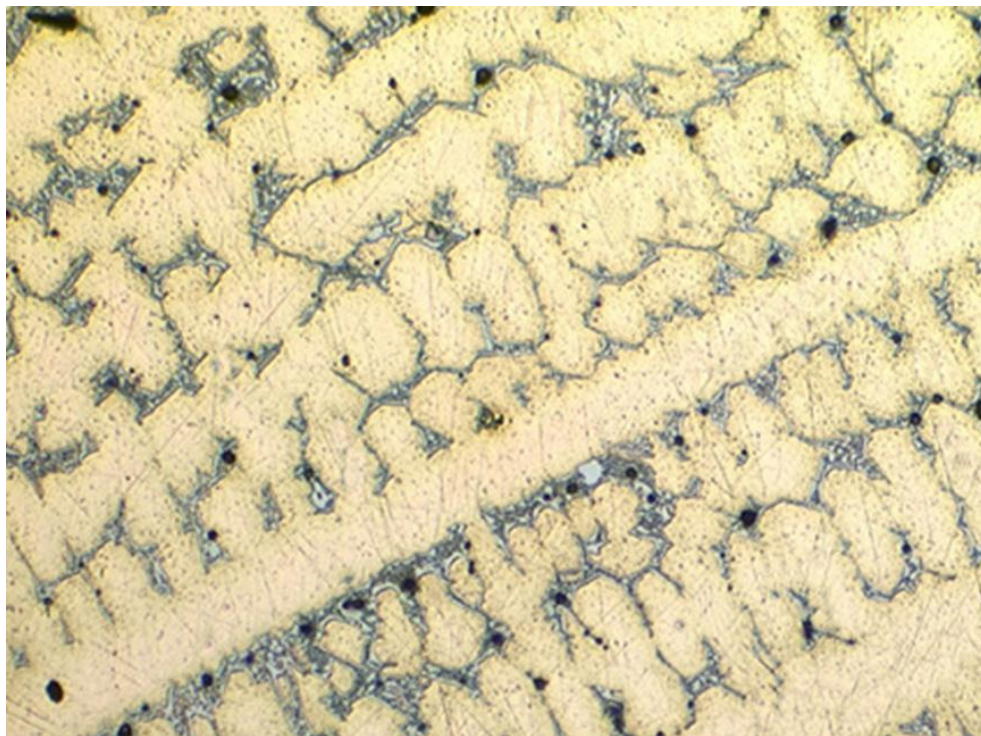


Figure 4.18. 15% Sn bronze cast in an unpreheated mould and air-cooled, showing massive interdendritic eutectoid ($\alpha + \delta$). Image width 0.65mm

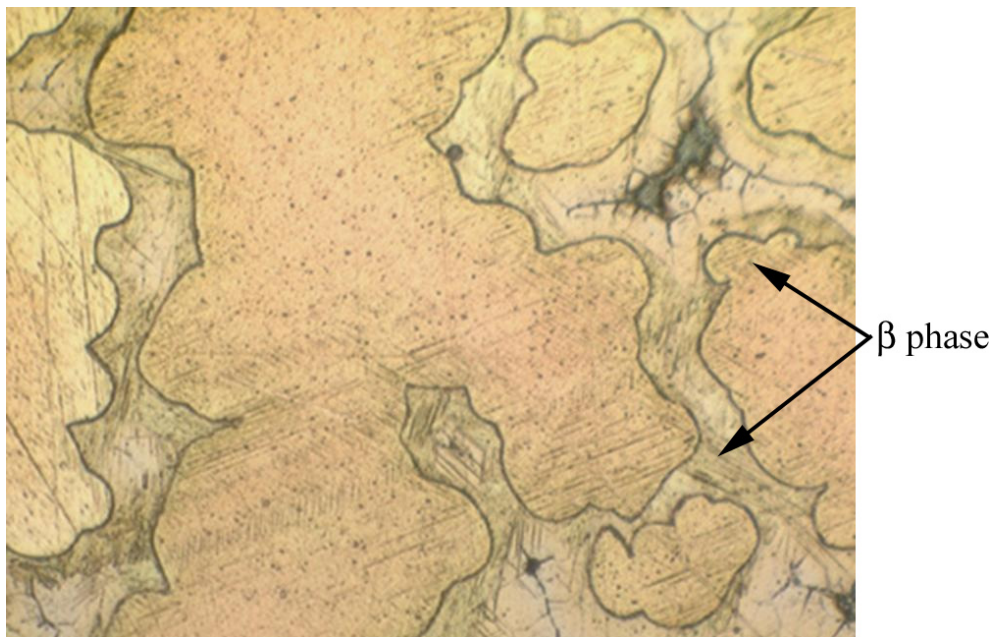


Figure 4.19. 15%Sn bronze cast in an unpreheated mould and water-quenched, showing β phase both interdentritically and within α grains. Image width 0.16mm

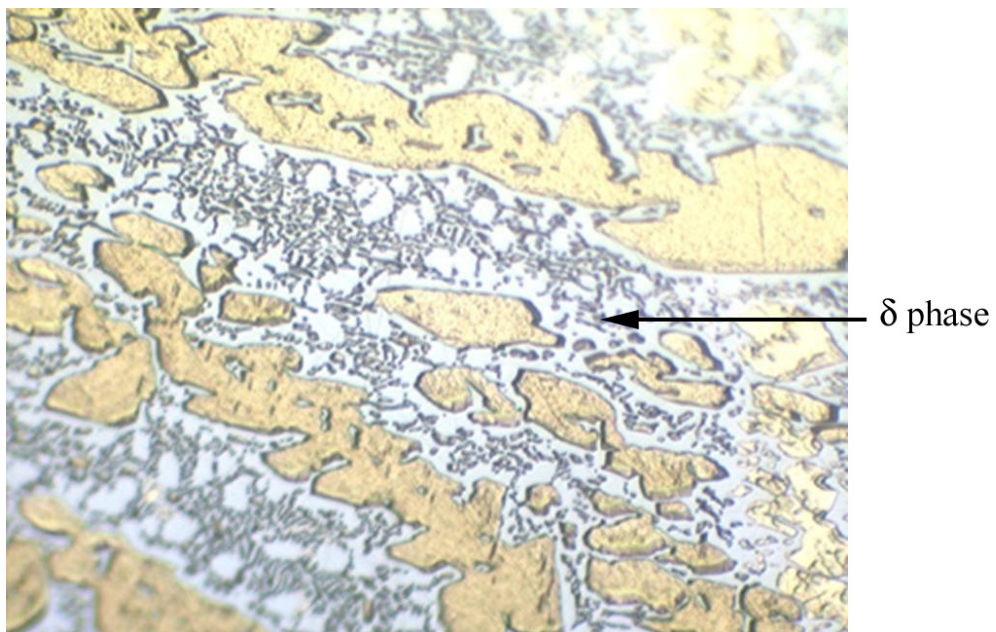


Figure 4.20. 23% Sn bronze cast in an unpreheated mould and air-cooled, showing massive δ phase. Image width 0.16mm

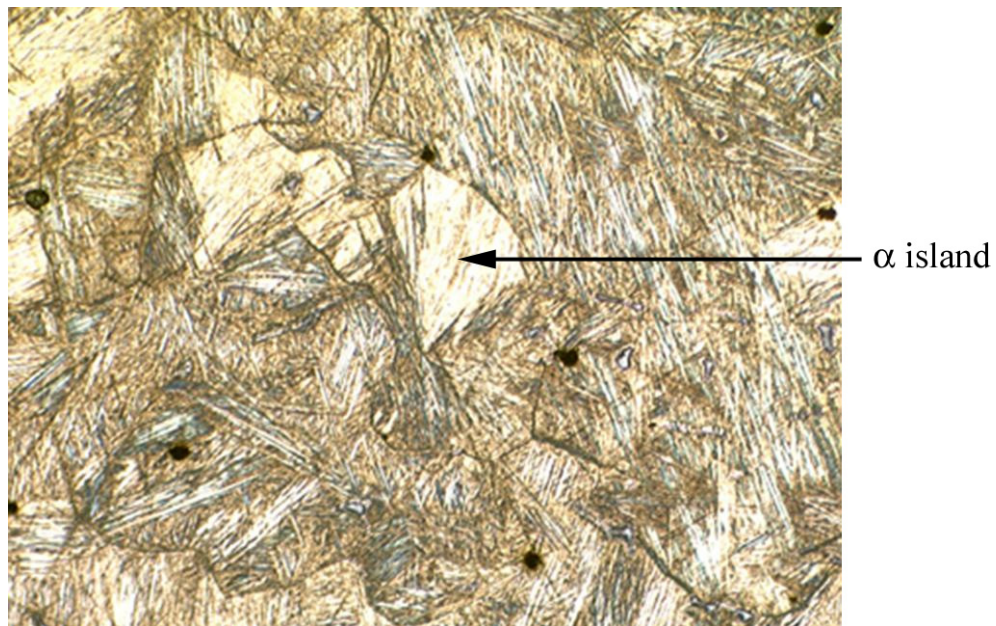


Figure 4.21. 23% Sn bronze cast in an unpreheated mould and water-quenched (sample No. 125), showing α islands in the matrix of needle β phase. Image width 1.3mm

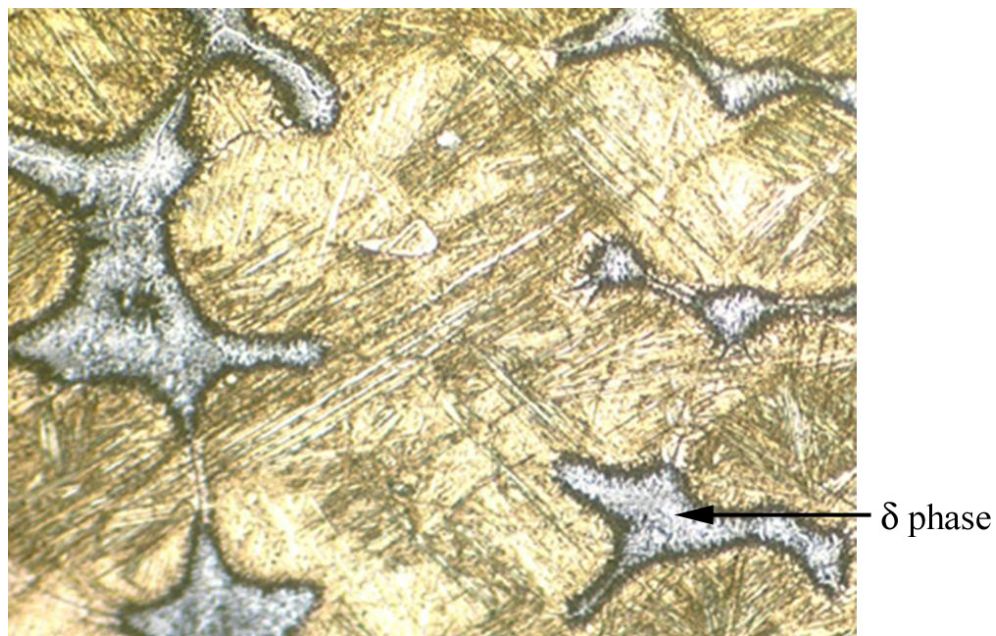


Figure 4.22. Same sample as figure 4.21, showing δ phase (gray dotted) in the matrix of β . Image width 0.33mm

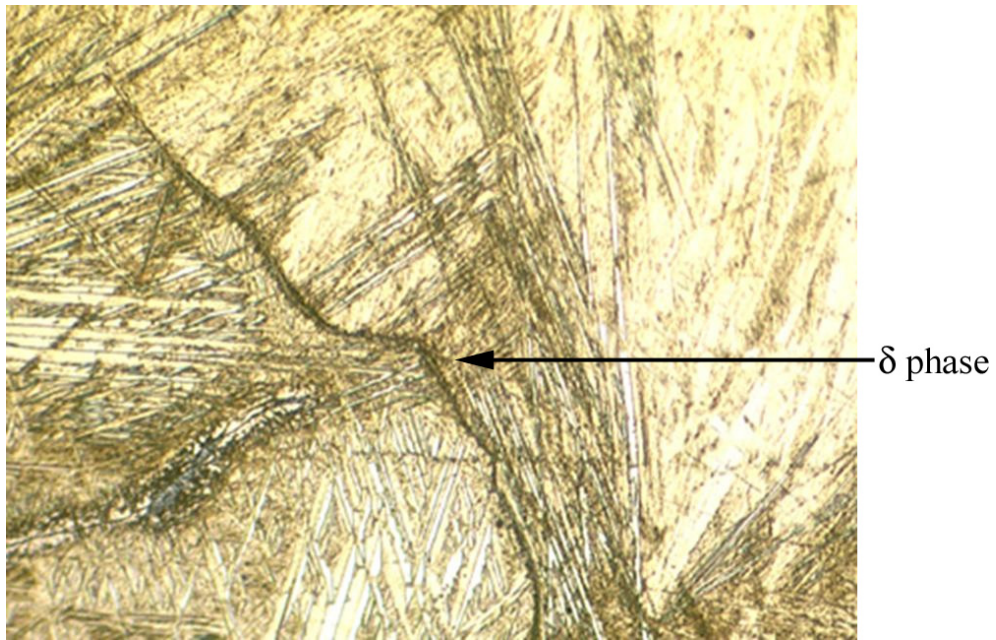


Figure 4.23. Same sample as figure 4.21, showing δ phase on the grain boundaries (dark line). This was confirmed by SEM/EDS analysis. Image width 0.33mm



Figure 4.24. Bronze of 2%Sn + 6%Pb cast in a preheated mould and air-cooled, showing a granular structure. Image width 1.3mm

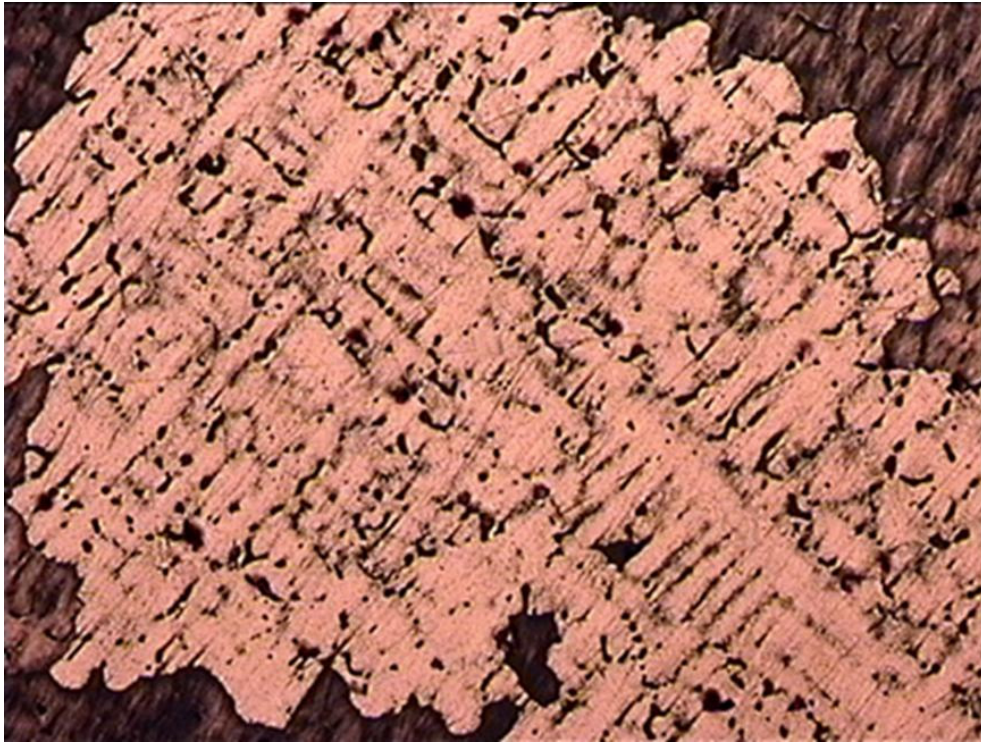


Figure 4.25. Bronze of 2%Sn + 6%Pb cast in an unpreheated mould and air-cooled, showing a dendritic structure.
Image width 1.3mm



Figure 4.26. Bronze of 2%Sn + 10%Pb cast in an unpreheated mould and air-cooled, showing granular structure and Pb on grain boundaries. Image width 0.65mm

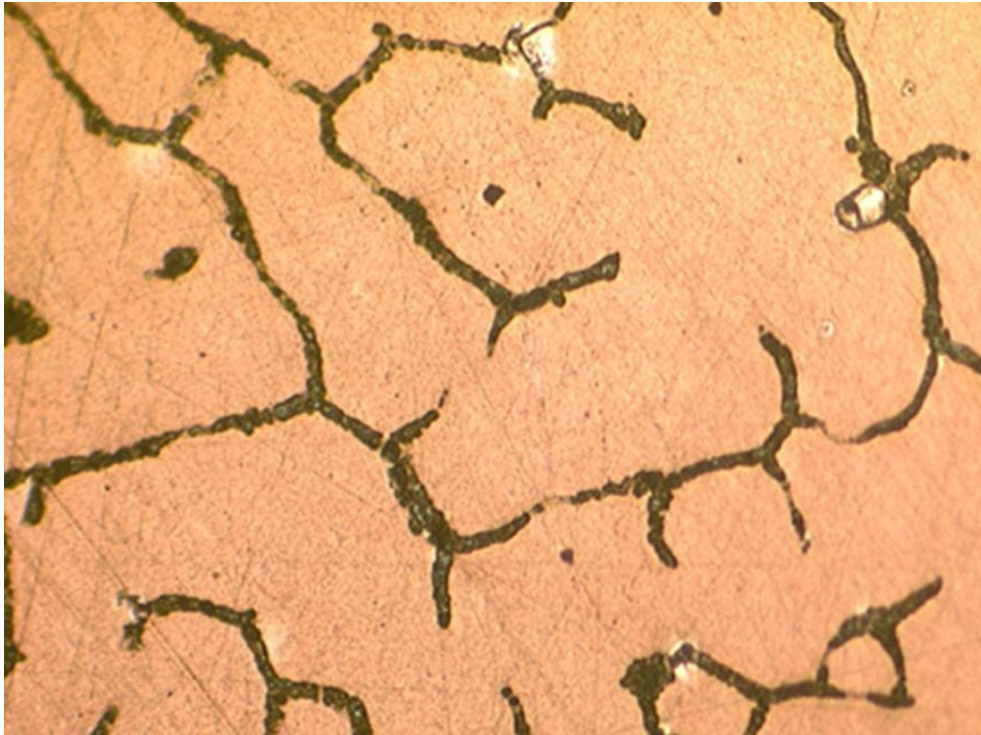


Figure 4.27. Bronzes of 2%Sn + 2%Pb cast in an unpreheated mould and water-quenched (sample No.128), showing a dendritic structure. Pb is almost indistinguishable from the dark phase in the interdendritic regions. Image width 0.33mm



Figure 5.1 Drag box with the pattern



Figure 5.2 Completed drag box



Figure 5.3 Completed drag and cope boxes for bronze mould

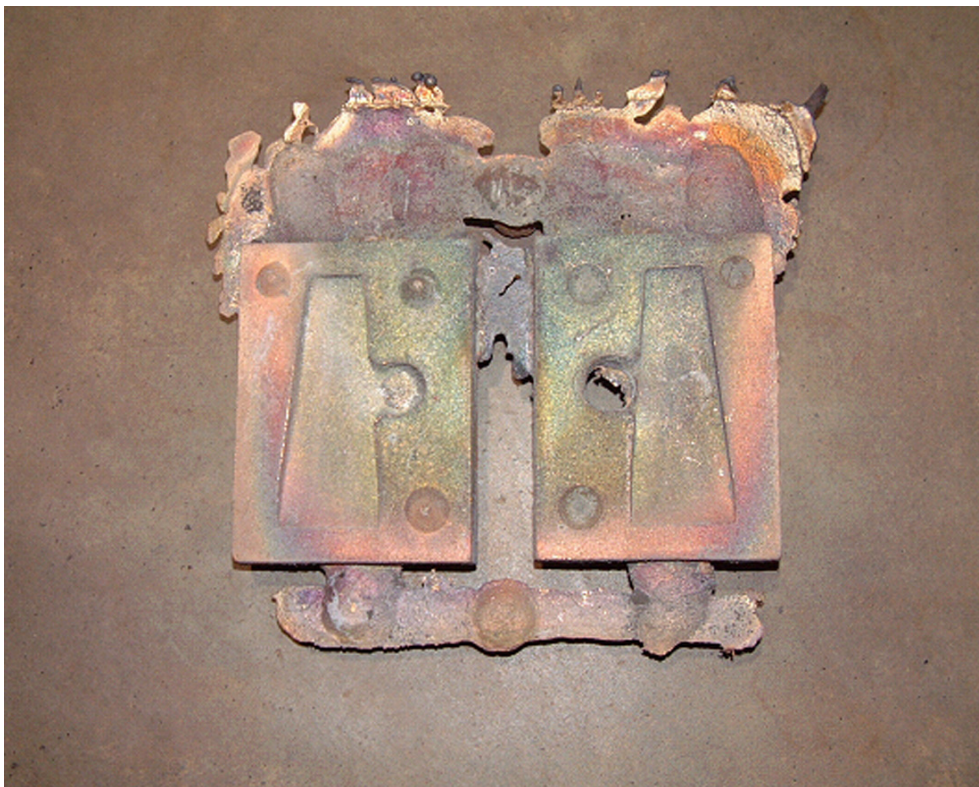


Figure 5.4 The two halves of the first bronze mould with flashing



Figure 5.5 Finished two halves of the first bronze mould



Figure 5.6 The first bronze mould, viewed from top



Figure 5.7 Flame-warmed bronze moulds ready for casting

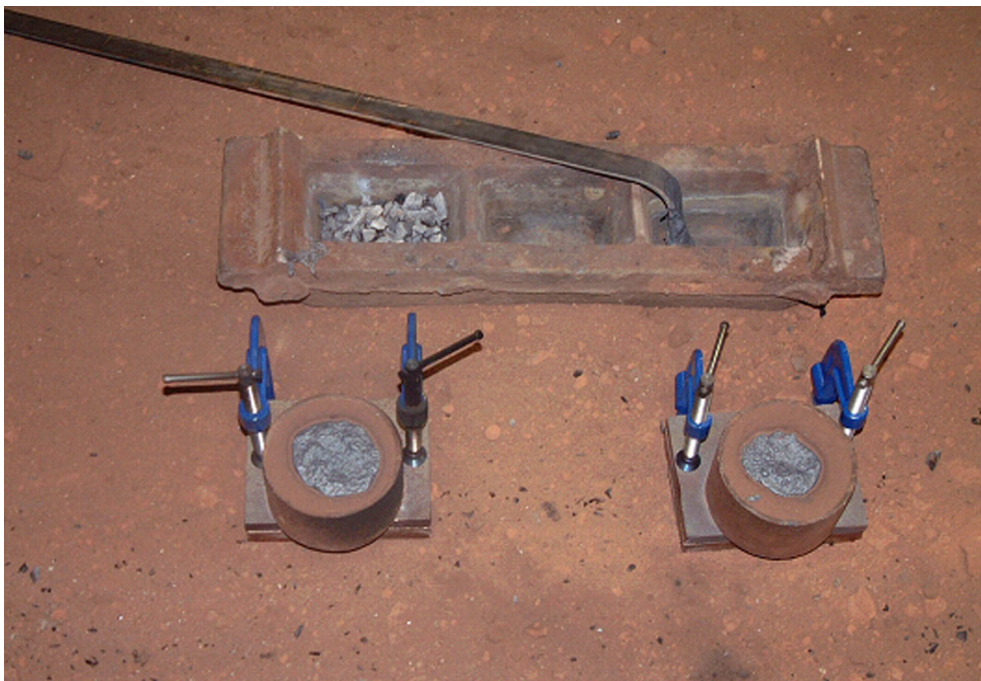


Figure 5.8 The clamped moulds after casting with a reservoir of metal filling the runner bush

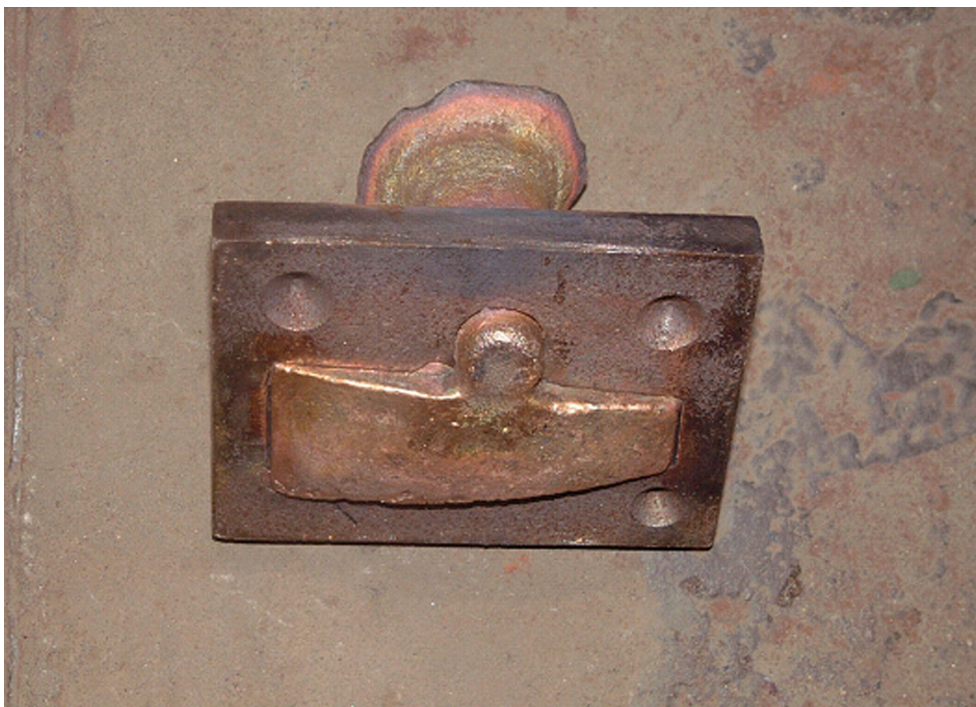


Figure 5.9 Solidified feeder and runner bush attached to the upper part of the first mould

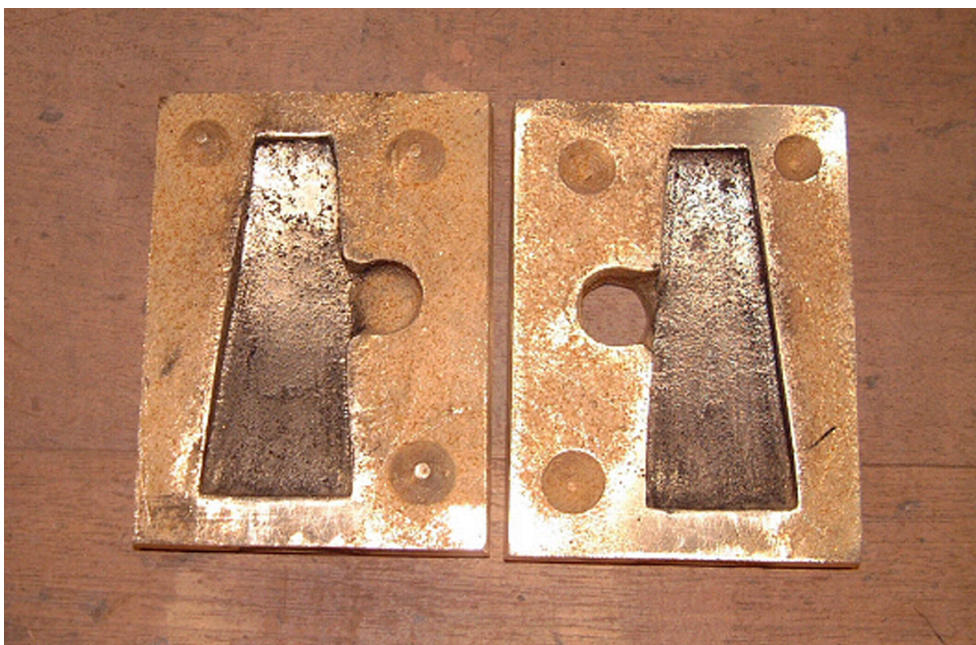


Figure 5.10 The first mould after one use



Figure 5.11 Funnel-shaped feeders cut at sides of bronze mould halves

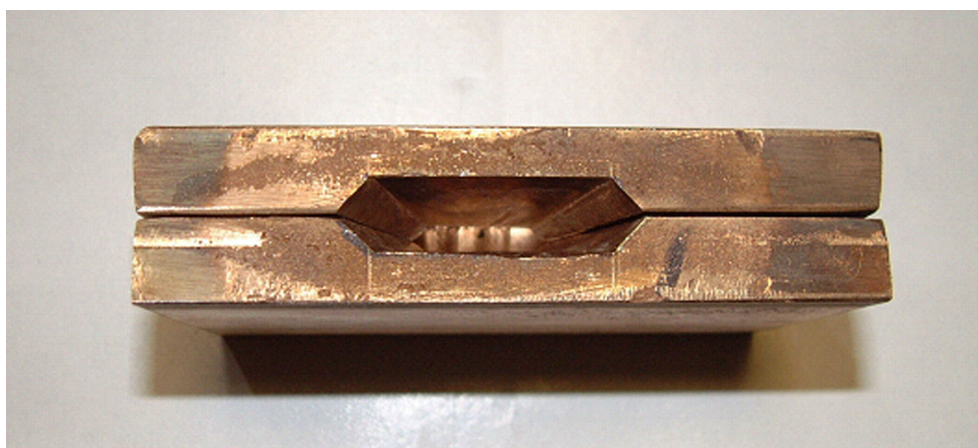


Figure 5.12 Side view of the second mould with the feeder at the side



Figure 5.13 The damaged mould after having been used for ten castings



Figure 5.14 An axe with feeder cast in a bronze mould



a



b

Figure 5.15 An axe cast in a bronze mould after sand blasting

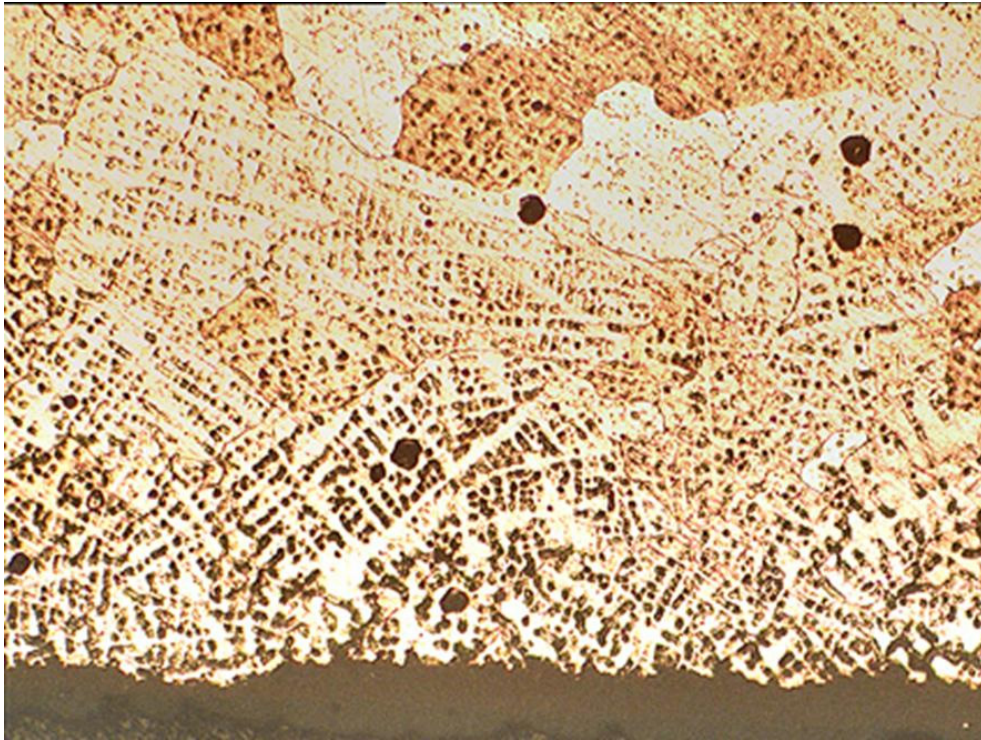
a. top view; b. side view, showing casting seam



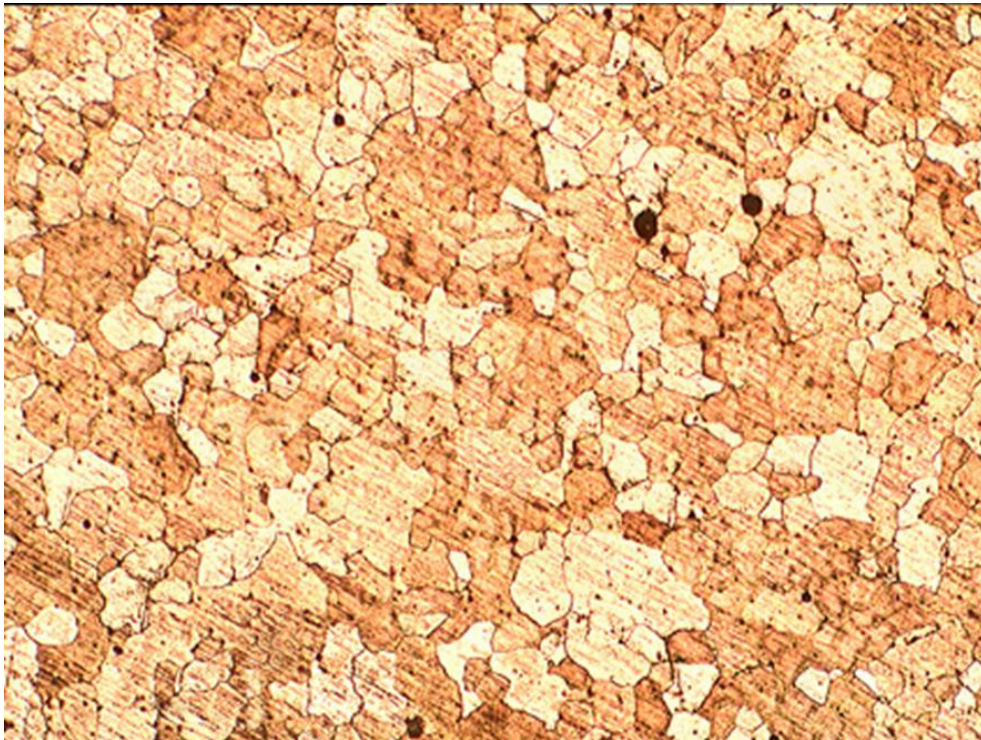
Figure 5.16 Photomicrograph of 2% Sn bronze, mould preheated to 350°C, showing a dendritic structure. Image width 1.3mm.



Figure 5.17 Photomicrograph of 10% Sn bronze, mould preheated to 350°C, showing a dendritic structure. The dendrites are finer but longer than those in figure 5.16. Image width 1.3mm.



a.



b

Figure 5.18 Photomicrographs of 2% Sn bronze, mould warmed by flame, showing a dendritic structure on the surface (a) and a granular structure in the centre (b). Image width 1.3mm.

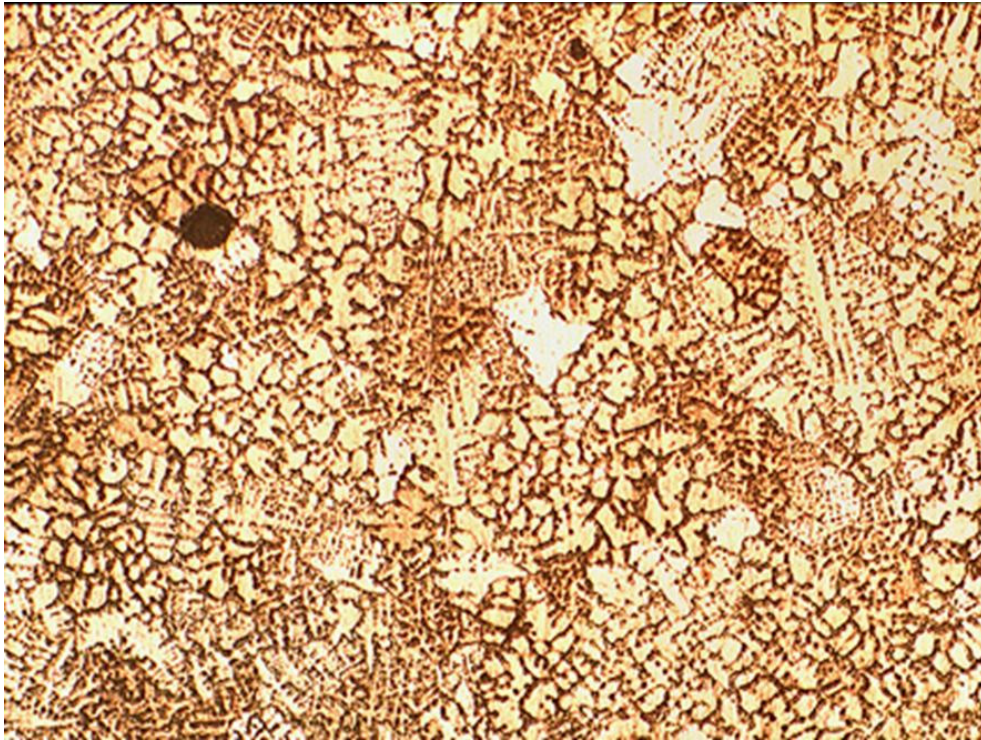


Figure 5.19 Photomicrograph of bronze with 2%Sn + 2%Pb, mould warmed by flame, showing both coarse and fine dendrites. Image width 1.3mm.

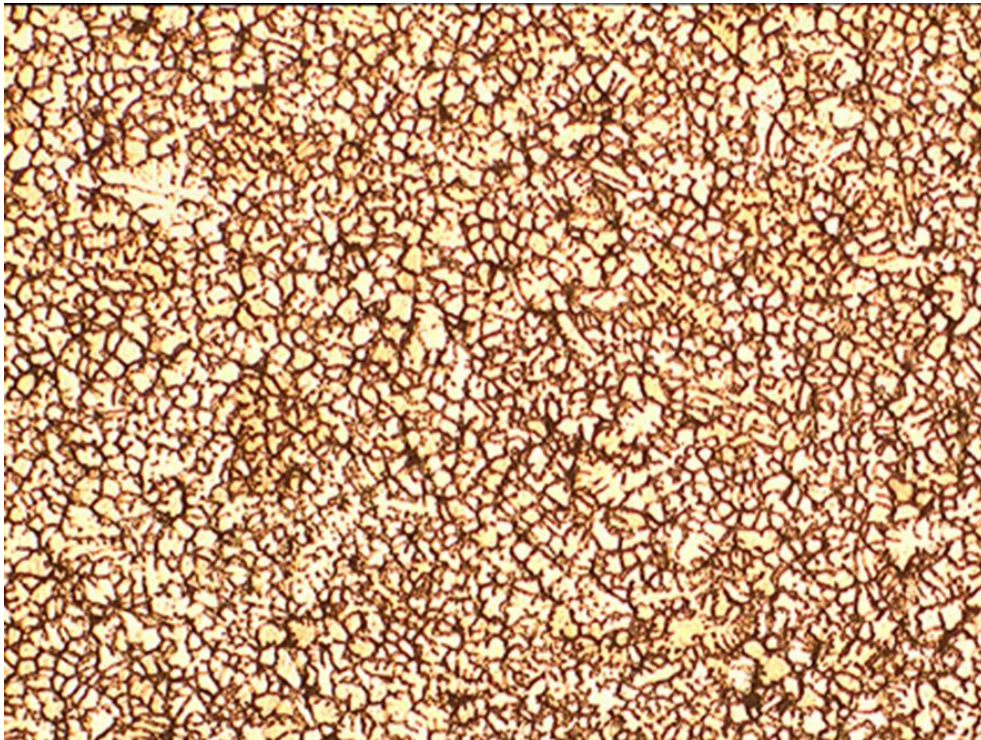
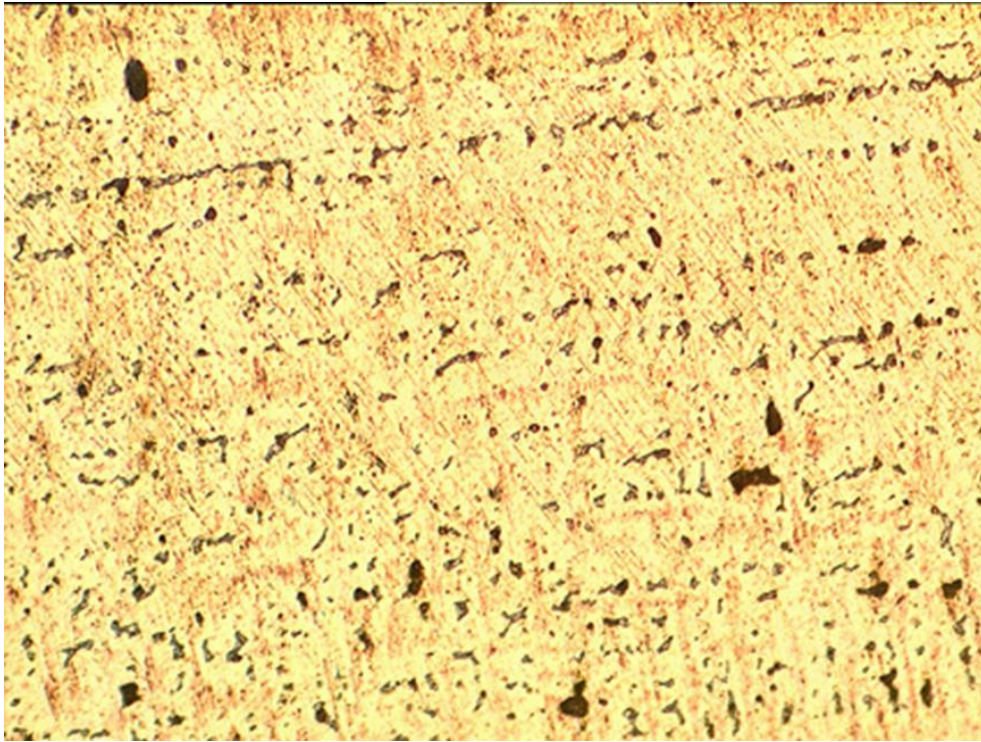
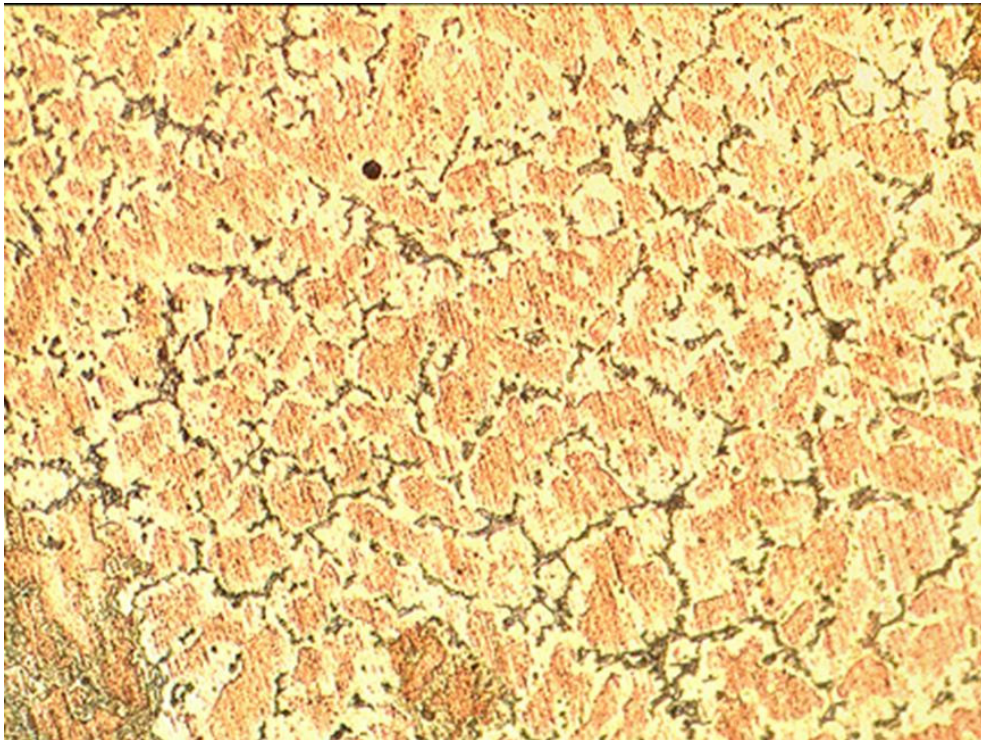


Figure 5.20 Photomicrograph of bronze with 2%Sn + 10%Pb, mould preheated to 350°C, showing coarse but short dendrites. Image width 1.3mm.

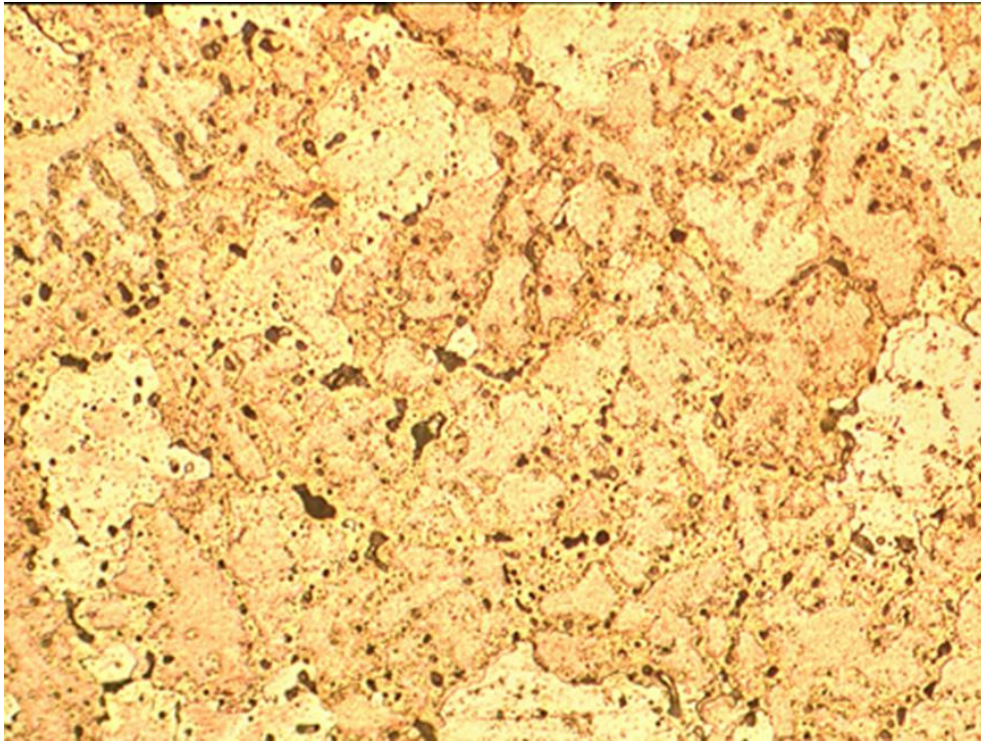


a. mould preheated to 350°C

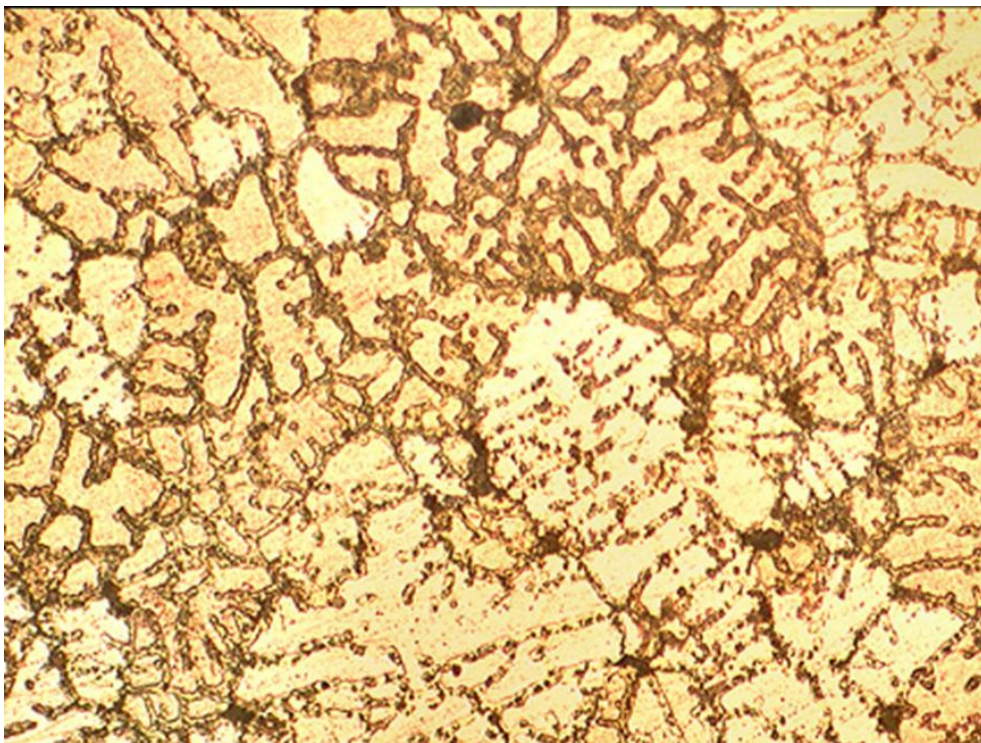


b. mould flame warmed

Figure 5.21 Photomicrographs of 10% Sn bronzes, showing more pronounced ($\alpha+\delta$) eutectoids in the bronze cast in the flame-warmed mould than in that cast in the preheated mould. Image width 0.33mm.

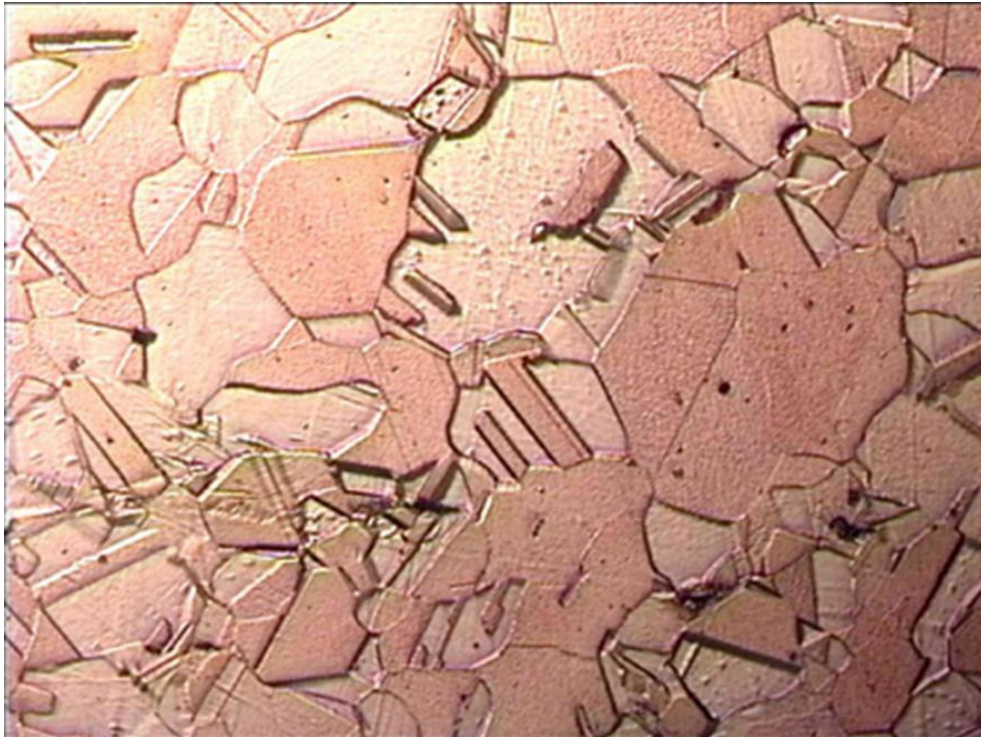


a. mould preheated to 350°C

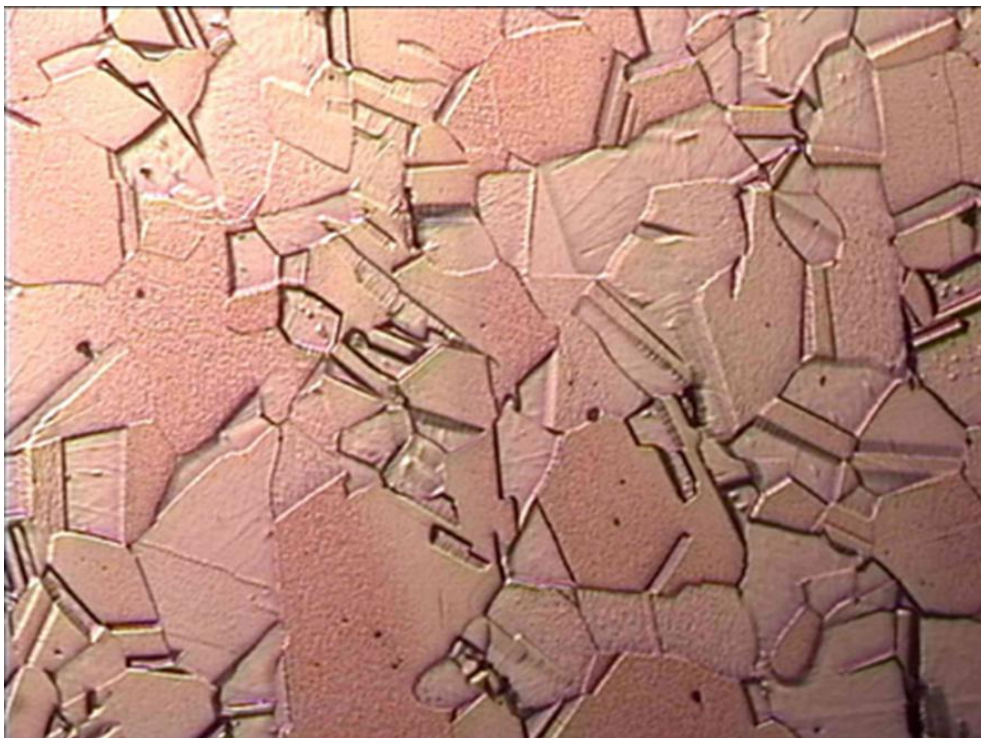


b. mould flame warmed

Figure 5.22 Photomicrographs of bronzes with 6%Sn+6%Pb, showing more pronounced dendritic structure and $(\alpha+\delta)$ eutectoids in the bronze cast in the flame-warmed mould (b) than in that cast in the preheated mould (a). Image width 0.33mm.

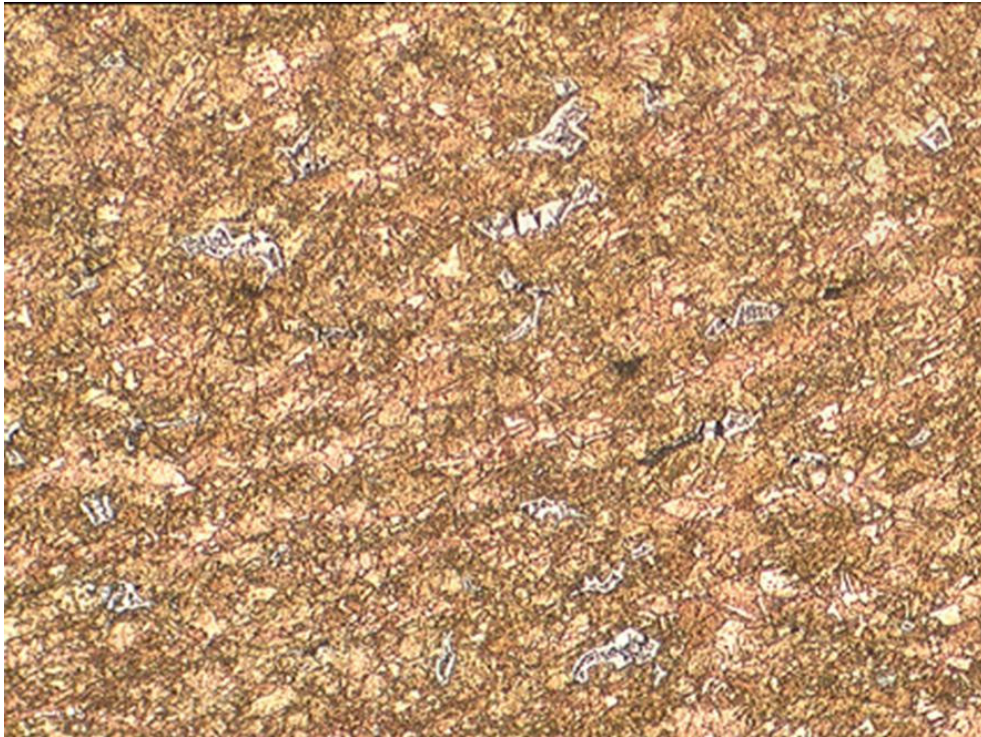


a: annealed at 550°C for 15 minutes. Image width 0.13mm.

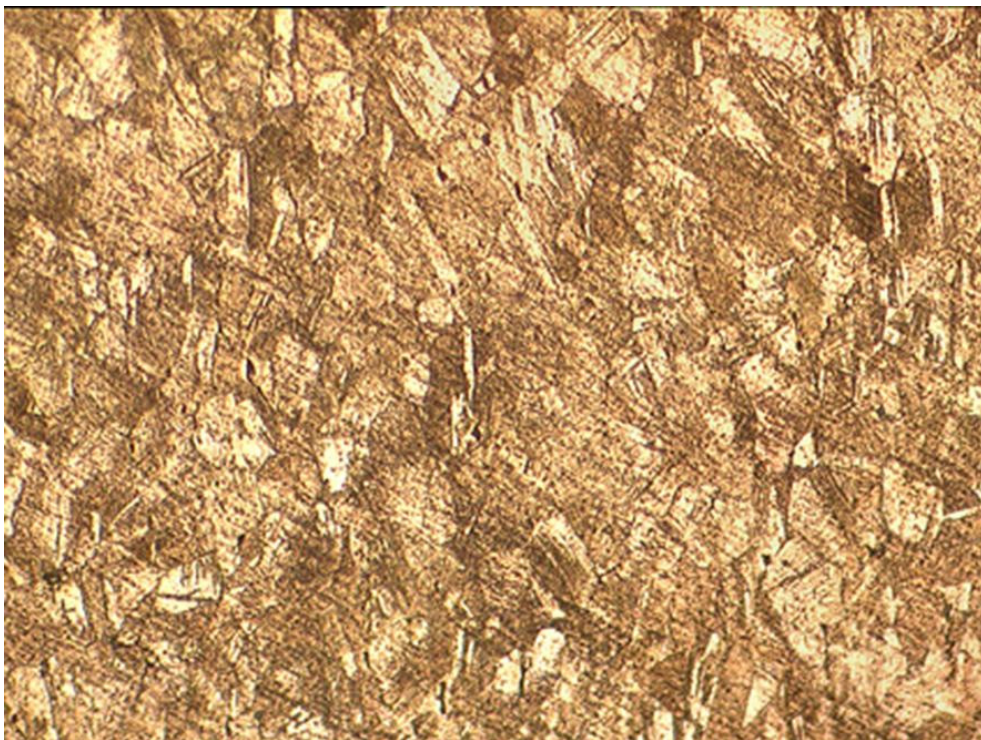


b: annealed at 650°C for 15 minutes. Image width 0.13mm.

Figure 7.5. Photomicrographs of 40% cold worked and annealed 6%Sn bronze (cast in sand and air-cooled), showing a fully recrystallised structure and annealing twins.

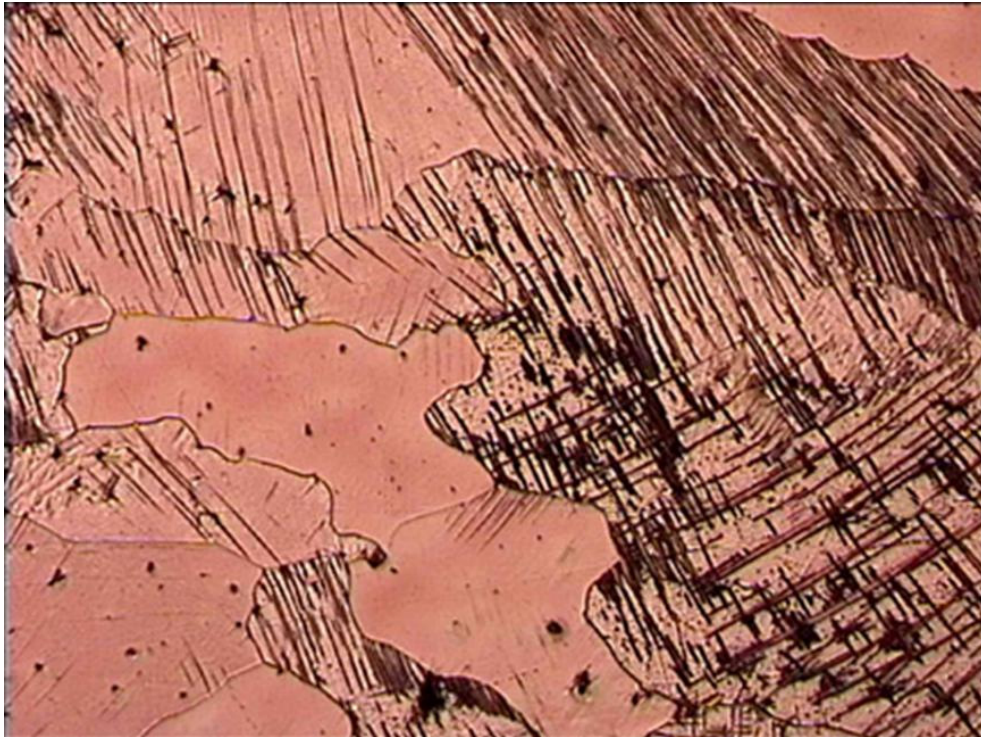


a: annealed at 600°/15minutes showing an incomplete recrystallisation with considerable amount of $\alpha+\delta$ eutectoids.
Image width 0.13mm.

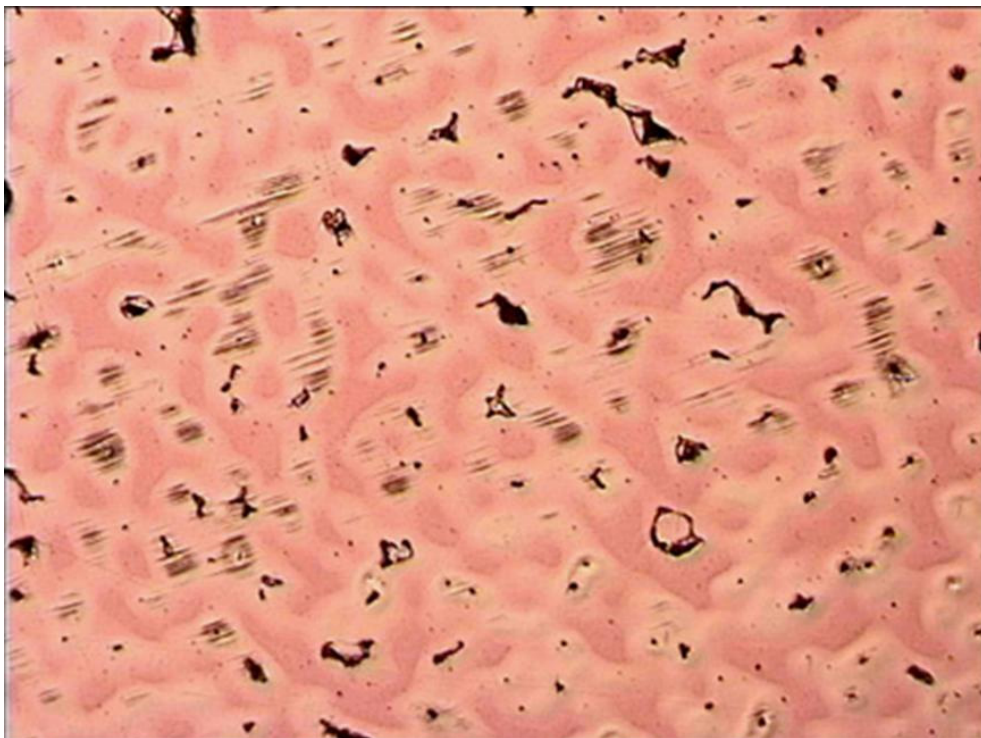


b: the above sample after annealing at 650°/15minutes showing complete recrystallisation. The slip lines were due to a further reduction after the annealing

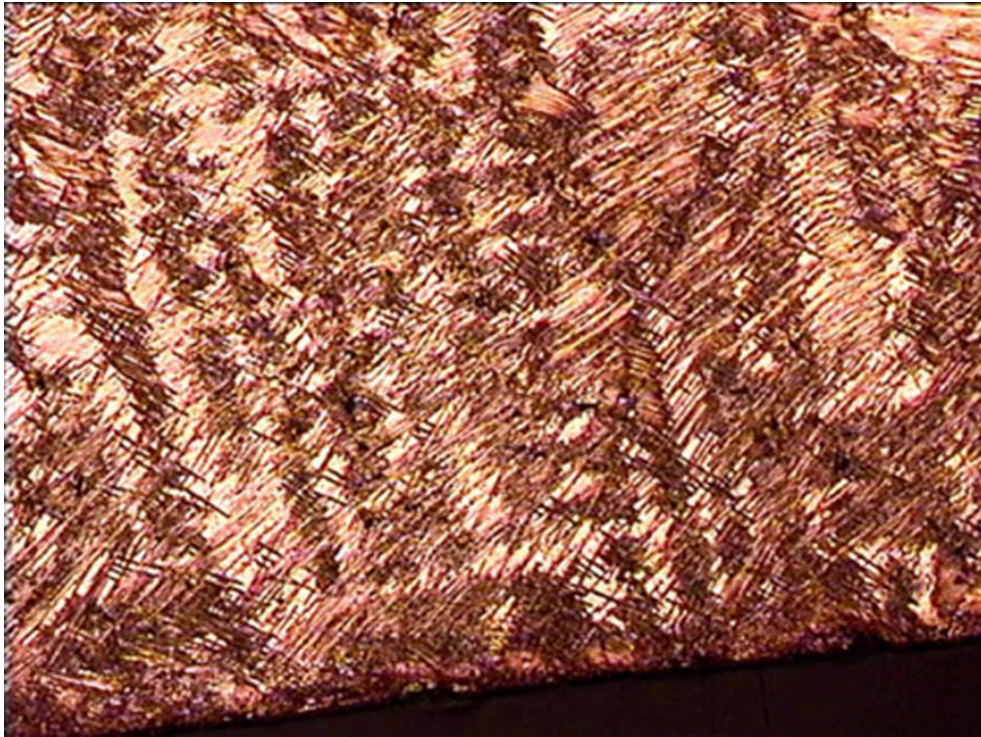
Figure 7.6 Photomicrographs of a 30% cold worked 10%Sn bronze after a cycle of rolling and annealing



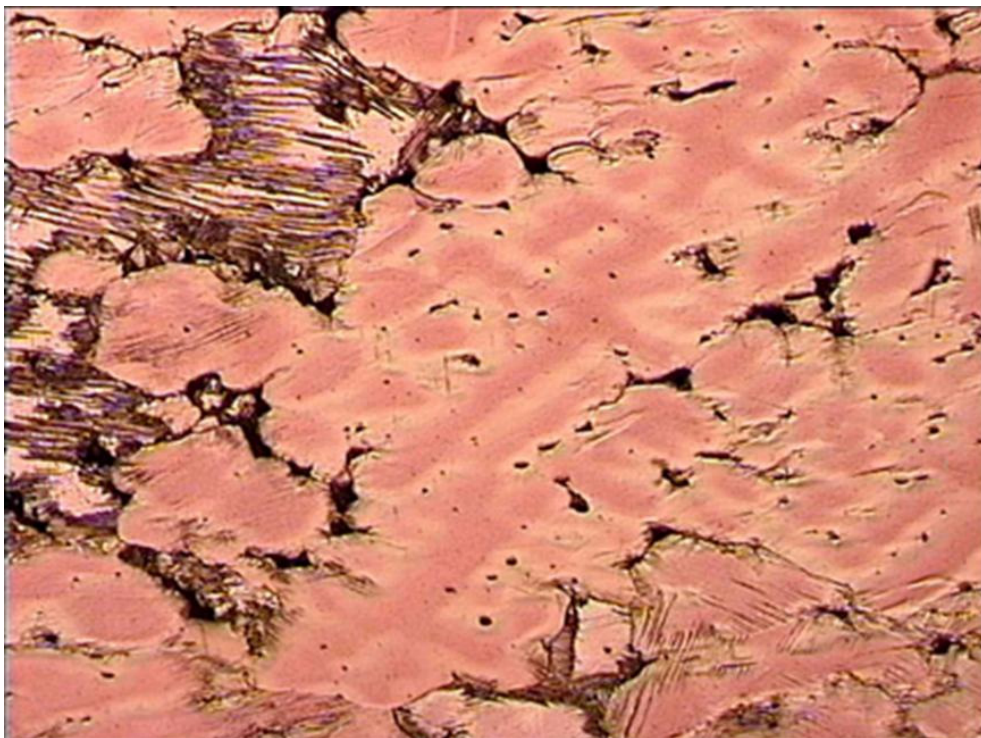
a: 10% reduction, surface of sample. Image width 0.65mm



b: 10% reduction, centre of sample. Image width 0.65mm



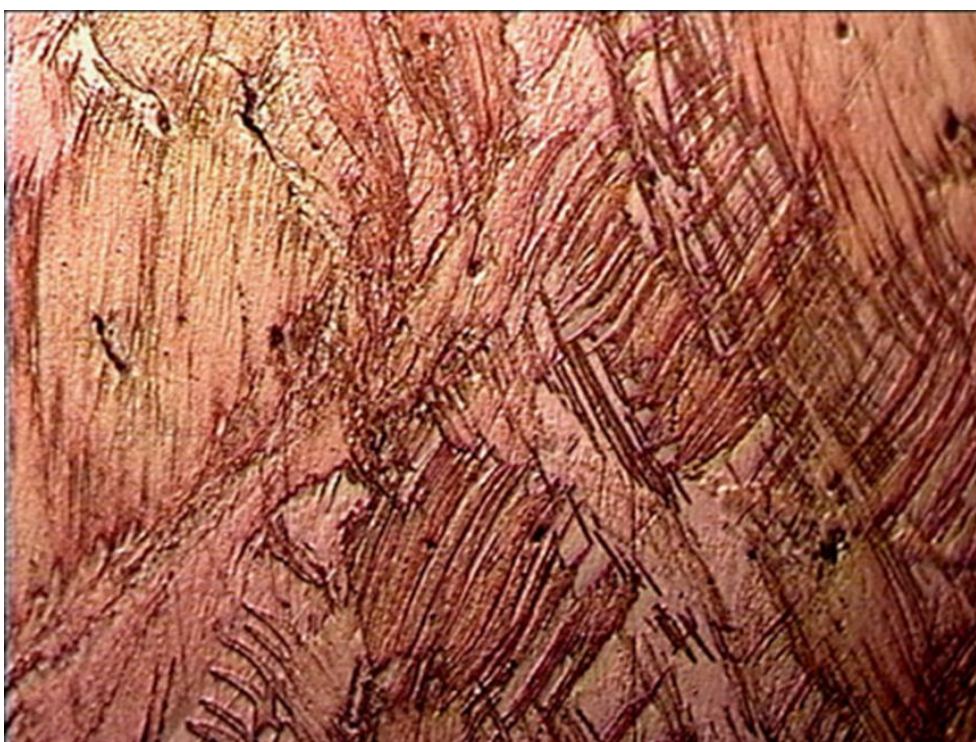
c: 30% reduction, surface of sample. Image width 0.65mm



d: 30% reduction, centre of sample. Image width 0.65mm



e: 45% reduction, surface of sample. Image width 0.13mm



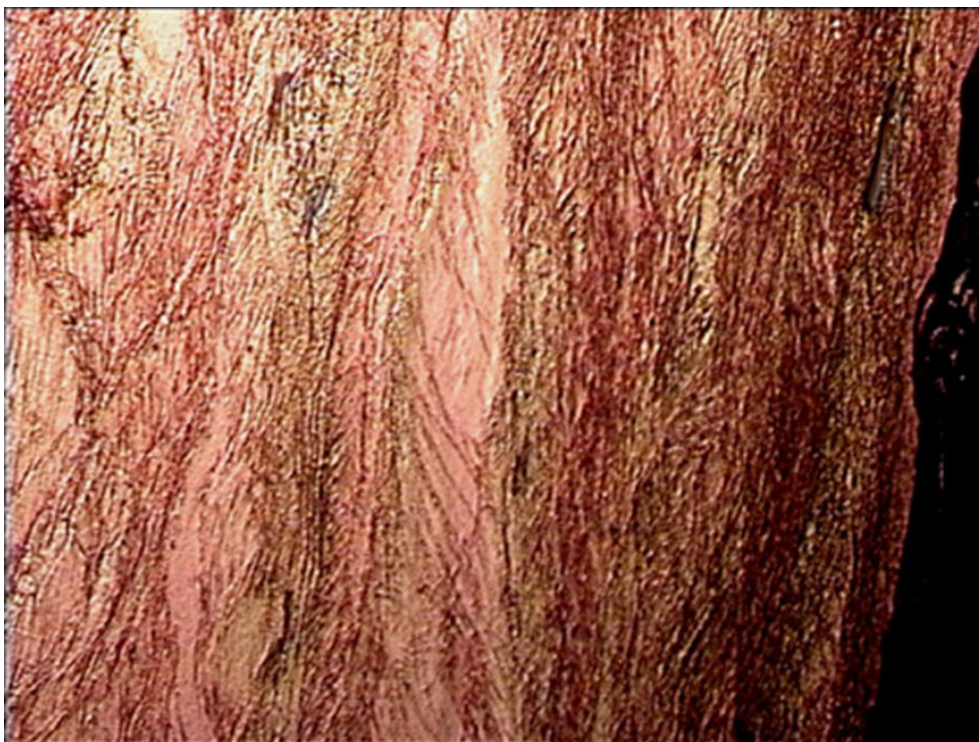
f: 45% reduction, centre of sample. Image width 0.13mm



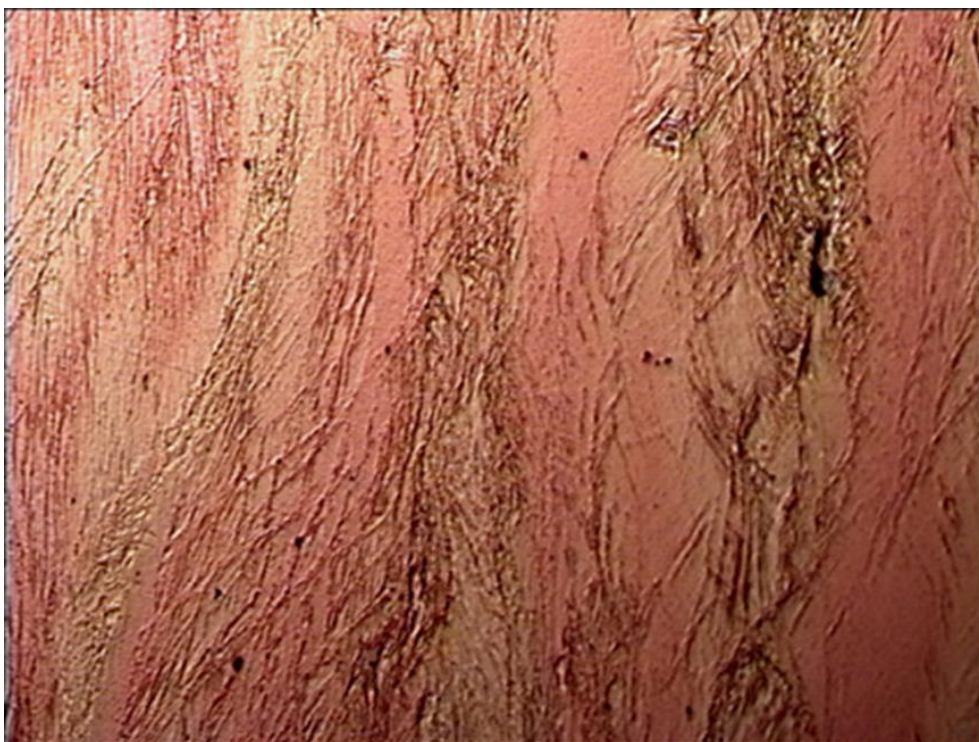
g: 60% reduction, surface of sample. Image width 0.13mm



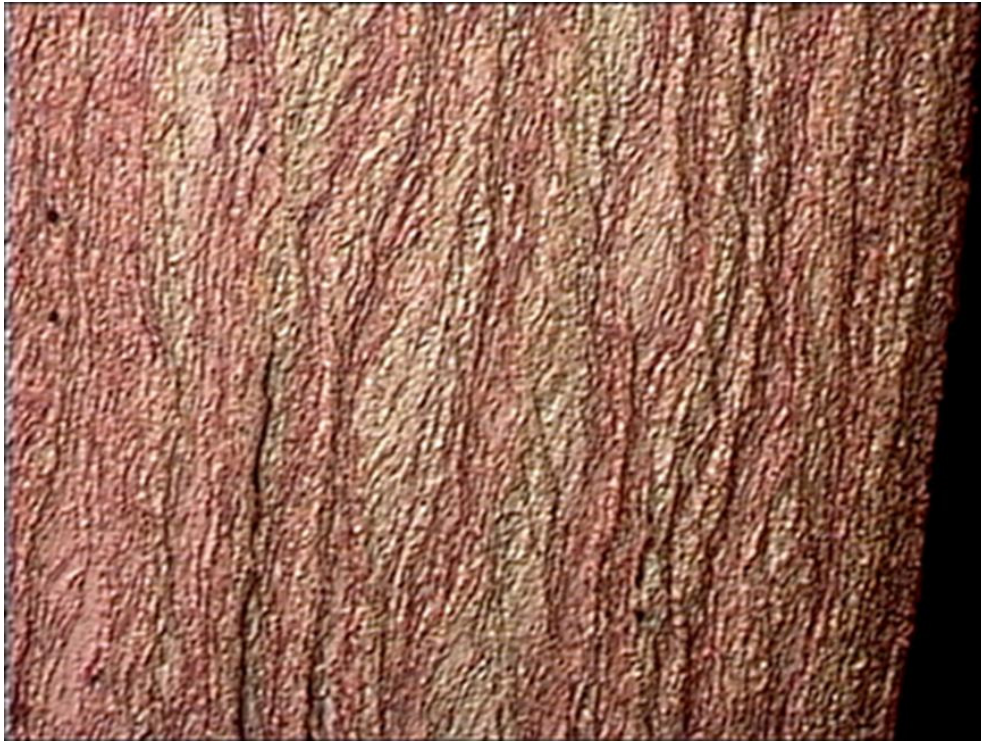
h: 60% reduction, centre of sample. Image width 0.13mm



I: 80% reduction, surface of sample. Image width 0.13mm



j: 80% reduction, centre of sample. Image width 0.13mm



K: 90% reduction, surface of sample. Image width 65 μ m



I: 90% reduction, centre of sample. Image width 65 μ m

Figure 7.7. Photomicrographs of 6%Sn bronze (cast in sand and air-cooled) at various reduction rates by cold rolling without annealing



Figure 7.8. Photomicrograph of the bronze containing 10%Sn and 2%Pb (cast in sand and air-cooled), showing slip lines on the surface caused by sand gritting employed for cleaning the surface.
Image width 0.65mm.

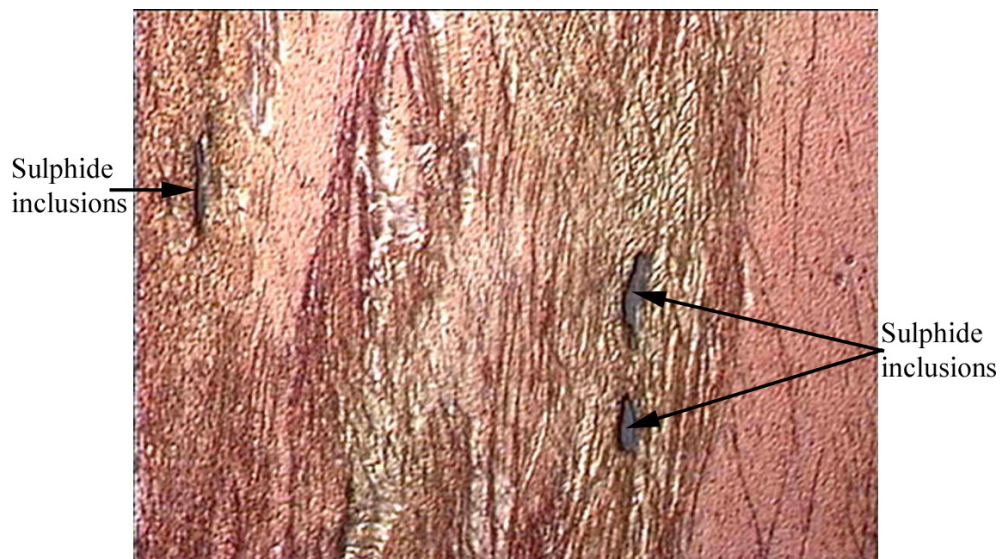


Figure 7.9. Photomicrograph of the cold worked bronze with 60% reduction containing 6%Sn (cast in clay and air-cooled), showing elongation of sulphide inclusion. Image width 0.13mm.

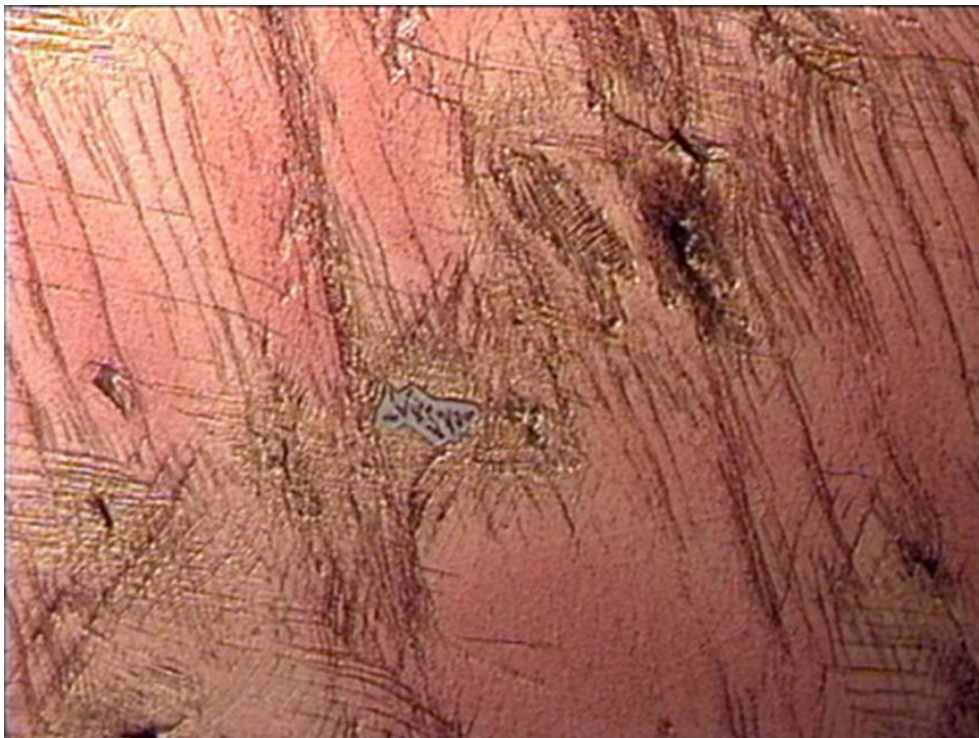


Figure 7.10. Photomicrograph of the cold worked bronze with 60% reduction containing 6%Sn (cast in clay and air-cooled), showing unaffected $\alpha + \delta$ eutectoid. Image width 0.13mm.