**Stainless Steel Casting Alloys: Metallographic Techniques and Microstructures**
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## Atlas of Microstructures for Stainless Steel Casting Alloys

**Fig. 1** CA-6NM alloy, normalized 1 h at 1010 °C (1850 °F) and tempered 2 h at 650 °C (1200 °F). Structure consists of tempered martensite. Vilella's reagent. 400×

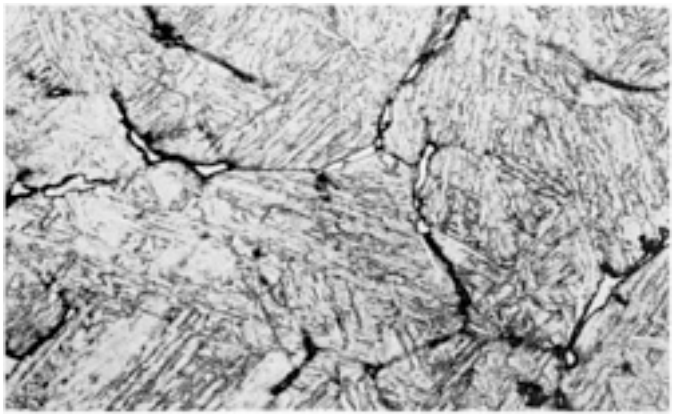

**Fig. 2** CA-6NM alloy, 75-mm (3-in.) thick section, as-cast. Cooling rate was very slow (casting was made in a sand mold). Precipitated chromium carbide particles (dark) and ferrite (white) are present at grain boundaries in a matrix of low-carbon martensite. See also Fig. 3. Vilella's reagent. 200×

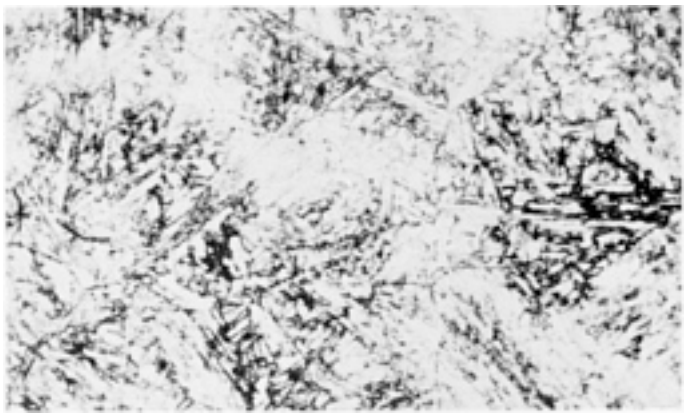

**Fig. 3** Same alloy and section thickness as for Fig. 2, but heated to 1040 °C (1900 °F) and held 4 h, air cooled, tempered 5 h at 635 °C (1175 °F). The carbide particles at grain boundaries have dissolved during austenitizing; matrix consists of ferrite-free tempered martensite. Vilella's reagent. 500×

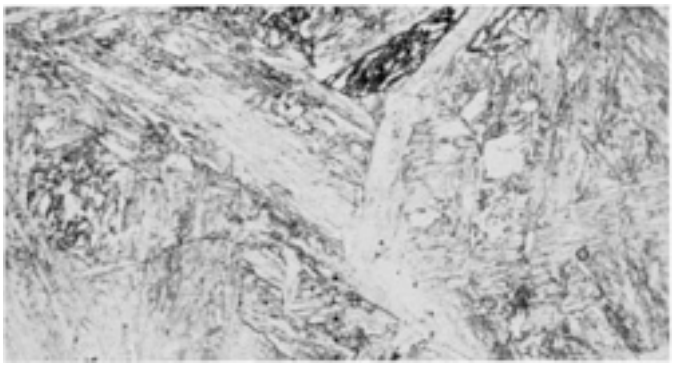

**Fig. 4** CA-6NM alloy, 75-mm (3-in.) thick section, heated to 1050 °C (1925 °F) and held 3 h, air cooled, tempered 1 h at 605 °C (11 25 °F). Ferrite-free tempered martensite, but coarser than in Fig. 3. See also Fig. 5. Vilella's reagent. 500×

**Fig. 5** Same alloy and heat treatment as for Fig. 4, but a section 150-mm (6-in.) thick. Some ferrite (note pool in upper right corner) is present in the tempered martensite matrix. Vilella's reagent. 500×

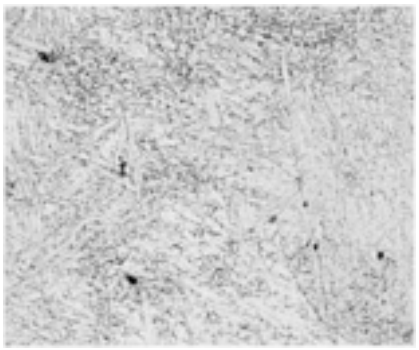

**Fig. 6** CA-15 alloy, normalized 4 h at 980 °C (1800 °F) and tempered 6 h at 705 °C (1300 °F). Structure consists of tempered martensite. Vilella's reagent. 400×

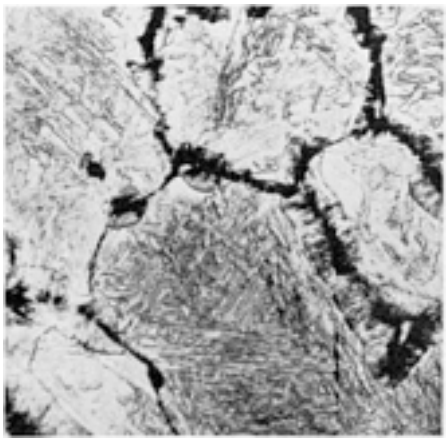

**Fig. 7** CA-15 alloy, 75-mm (3-in.) thick section, as-cast. Structure consists of islands of ferrite and dark-etching particles of chromium carbide at prior austenite grain boundaries in a matrix of martensite. See also Fig. 8 and 9. Vilella's reagent. 200×

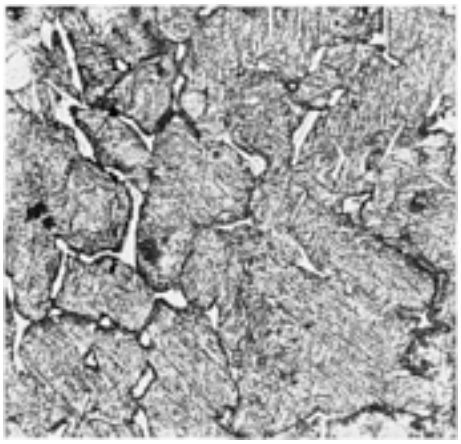

**Fig. 8** Same alloy, section thickness, and condition as Fig. 7, but a different casting, etchant, and magnification. Structure consists of islands of ferrite and grain-boundary carbide (dark) in martensite matrix. See Fig. 9. Ferric chloride. 100×

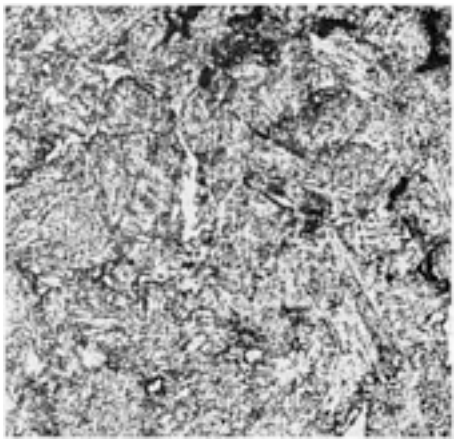

**Fig. 9** Same alloy and section thickness as for Fig. 8, but heated to 1040 °C (1900 °F) and held for 3 h, air cooled, tempered at 690 °C (1275 °F) for 4 h. Ferrite islands have blended with the tempered martensite matrix. Ferric chloride. 100×

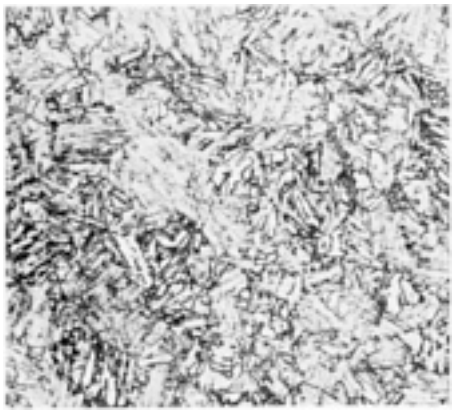

**Fig. 10** CA-15 alloy, 75-mm (3-in.) thick section, austenitized at 1010 °C (1850 °F), air cooled, tempered at 675 °C (1250 °F) for 4 h. The structure shows traces of ferrite in a matrix of tempered martensite. See also Fig. 11. Vilella's reagent. 200×

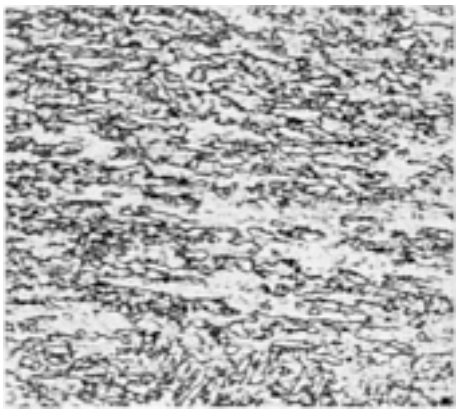

**Fig. 11** Same alloy, section thickness, and heat treatment as for Fig. 11, but at a higher magnification to emphasize the traces of ferrite in the tempered martensite matrix. Hardness of casting, 223 HB. Vilella's reagent. 500×

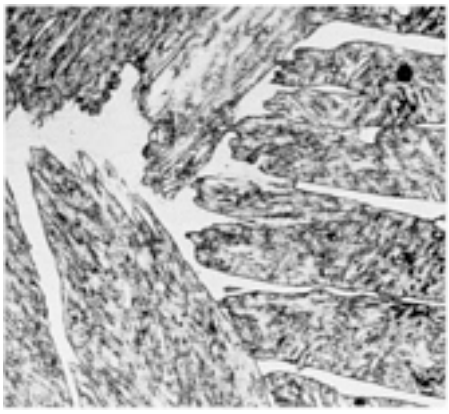

**Fig. 12** Same alloy and heat treatment as in Fig. 10, but for a 150-mm (6-in.) thick section, showing the effect of section thickness on structure. Islands of ferrite appear in the matrix of tempered martensite. See also Fig. 13. Vilella's reagent. 200×

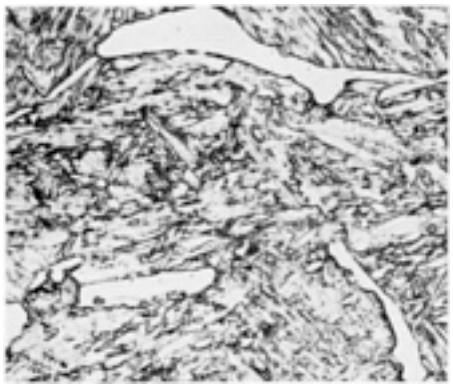

**Fig. 13** Same alloy, section thickness, and heat treatment as for Fig. 12, but at a higher magnification to reveal dispersed ferrite particles and massive ferrite stringers in the tempered martensite matrix. Vilella's reagent. 500×

**Fig. 14** CB-7Cu-1 alloy, as-cast. The structure consists of elongated pools of ferrite (light gray constituent) in a matrix of martensite, which varies in carbon content (as indicated by the response to etching). See also Fig. 15. Vilella's reagent. 500×

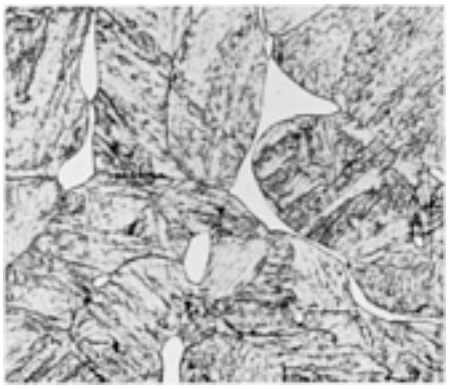

**Fig. 15** Same alloy as Fig. 14, but austenitized at 1050 °C (1925 °F) for 1 h and aged at 495 °C (925 °F). The matrix, tempered martensite, still contains ferrite pools (light), but shows less variation in carbon content. Vilella's reagent. 500×

**Fig. 16** CD-4MCu alloy, as-cast. Structure: jagged pools and particles of austenite in ferrite. Black specks are nonmetallic inclusions. Electrolytic: 10% $CrO_3$ at 6 V for 5 to 60 s. 500×

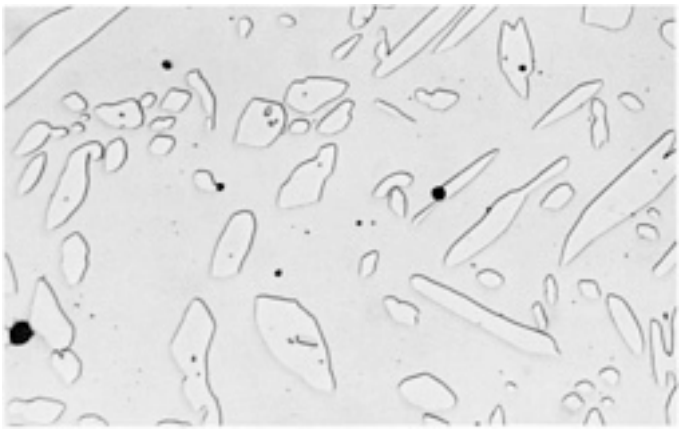

**Fig. 17** Same alloy as for Fig. 16, but solution treated at 1065 °C (1950 °F) for 1 h and water quenched. Shows effect of homogenization. Electrolytic: 10% $CrO_3$ at 6 V for 5 to 60 s. 500×

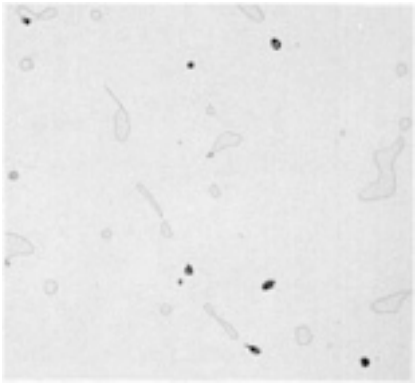

**Fig. 18** CF-3 alloy, solution treated 1 h at 1120 °C (2050 °F) and water quenched. Structure is austenite, with ferrite pools and inclusions. See also Fig. 19. Glyceregia. 400×

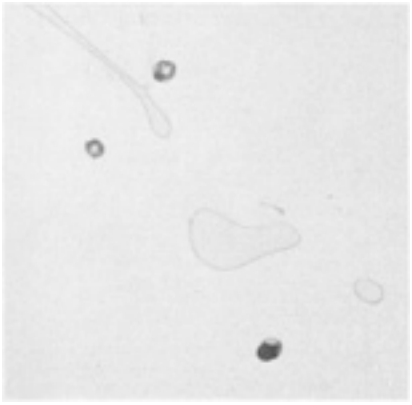

**Fig. 19** Same alloy and processing as Fig. 18. Higher magnification of ferrite pools and inclusions in austenite matrix. Glyceregia. 1000×

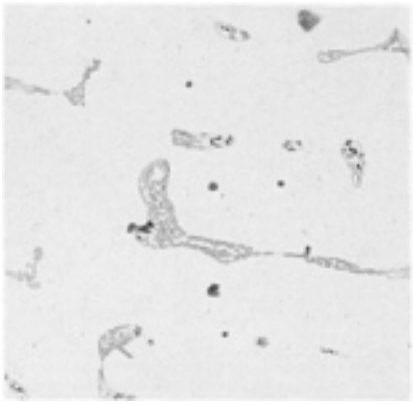

**Fig. 20** CF-3M alloy, solution treated 1 h at 1120 °C (2050 °F), water quenched and reheated 100 h at 760 °C (1400 °F). Structure is austenite matrix with some $\sigma$-phase present. See also Fig. 21. Electrolytic: NaCN. 400×

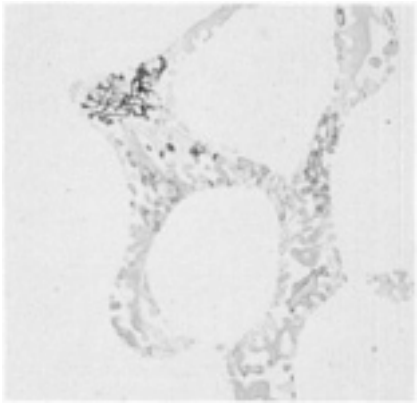

**Fig. 21** Same alloy and processing as Fig. 20. Higher magnification of $\sigma$-phase in austenite. Electrolytic: NaCN. 1000×

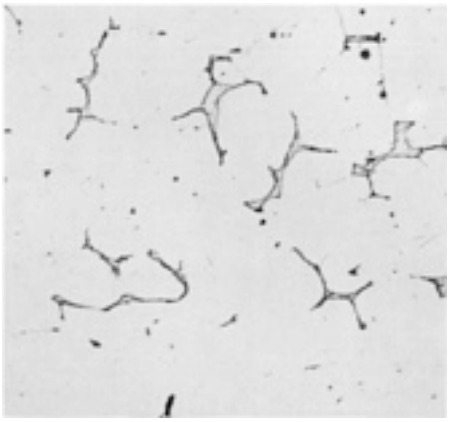

**Fig. 22** CF-3 alloy, 150-mm (6-in.) thick section, as-cast, showing dispersed islands of ferrite (5% by volume) and grain-boundary carbide particles in an austenite matrix. See also Fig. 23. HCl, $HNO_3$, acetic acid. 100×

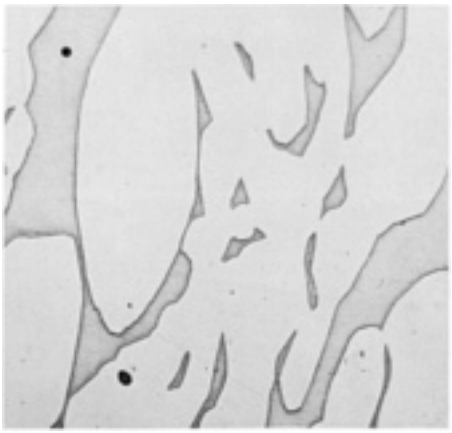

**Fig. 23** Same alloy and section thickness as for Fig. 22, but solution treated at 1120 °C (2050 °F) and water quenched. Specimen was taken from center of section. Elongated pools of ferrite in an austenite matrix (light). Electrolytic: 10N KOH. 250×

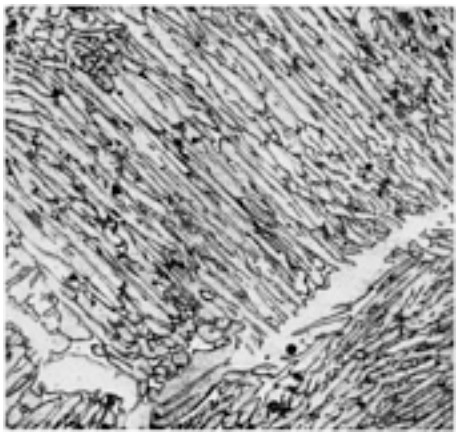

**Fig. 24** CF-3M alloy, as-cast. Specimen taken from a 25-mm (1-in.) thick section. Structure consists of a complex network of elongated ferrite in a matrix of austenite. Ferrite content is estimated at 22%. HCl, $HNO_3$, acetic acid. 100×

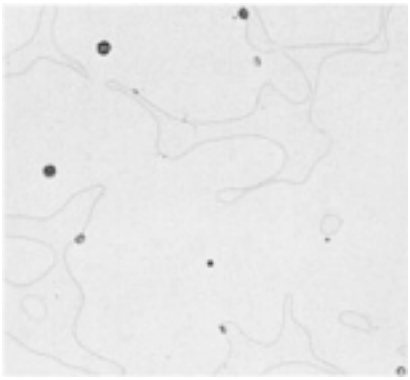

**Fig. 25** CF-8M alloy, solution treated 1 h at 1120 °C (2050 °F) and water quenched. Structure is austenite with ferrite and oxide inclusions. See also Fig. 26. Kalling's reagent. 400×

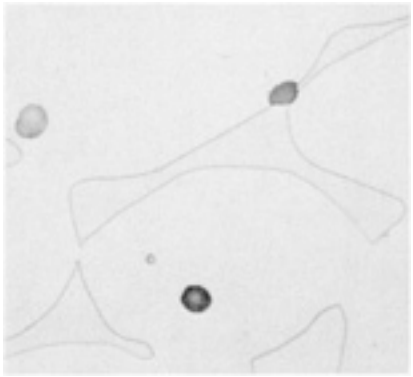

**Fig. 26** Same alloy and processing as Fig. 25, but a higher magnification view of the microstructure. Kalling's reagent. 1000×

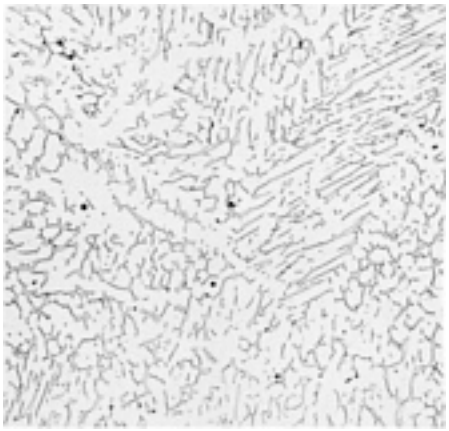

**Fig. 27** CF-8 alloy, 25-mm (1-in.) thick section, as sand cast. Structure contains 15 to 20% ferrite in an austenite matrix. Fig. 28 shows the sand cast alloy after solution treatment; Fig. 29 shows another as-cast structure. Electrolytic: oxalic acid. 80×

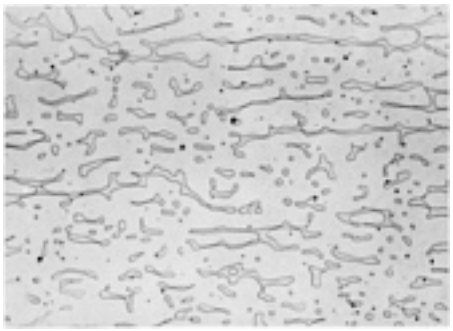

**Fig. 28** Same sand cast alloy and section thickness as Fig. 26, but solution treated 1 h at 1120 °C (2050 °F) and water quenched. Structure: pools of ferrite (outlined) in austenite; dendritic pattern has been altered. Glyceregia. 100×

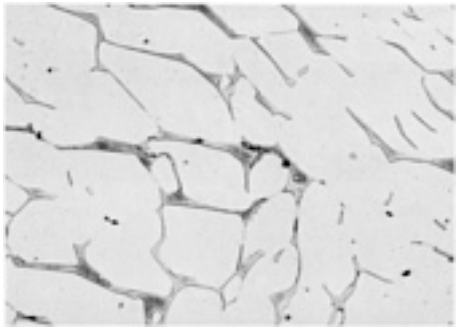

**Fig. 29** CF-8 alloy, 25-mm (1-in.) thick section, as-cast. The structure consists of a network of

ferrite (dark-etching islands) and some precipitated particles of carbide (dark spots) in a matrix of austenite (light gray background). Electrolytic: KOH; 3 V, 3 s. 200×

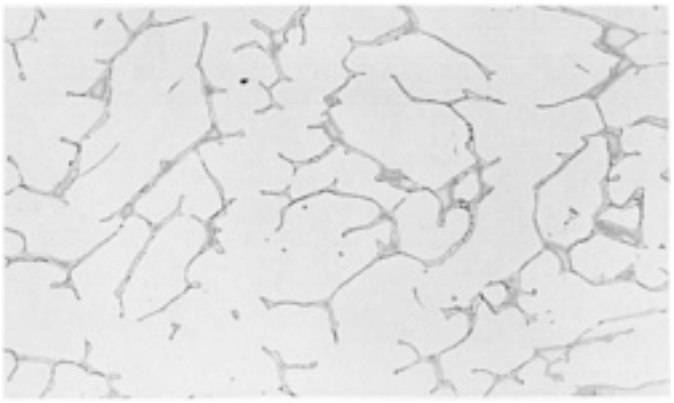

**Fig. 30** CF-8 alloy, 150-mm (6-in.) thick section, as-cast. Similar in ferrite distribution to Fig. 29. Note that chromium carbide particles have precipitated at the ferrite-austenite boundaries. Matrix is austenite. See also Fig. 31. Electrolytic: KOH. 200×

**Fig. 31** Same alloy and section thickness as for Fig. 30, but solution treated at 1075 °C (1970 °F) for 6 h and water quenched. Carbide particles have dissolved, but traces of ferrite network remain. Electrolytic: KOH. 300×

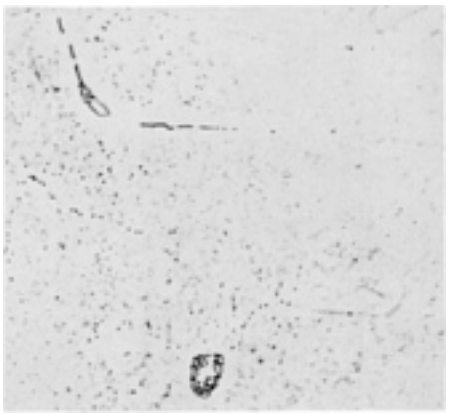

**Fig. 32** CF-8C alloy, solution treated at 1120 °C (2050 °F) for 1 h, water quenched, stabilized at 925 °C (1700 °F) for 1 h. Niobium carbide particles (black) precipitated during stabilization treatment at 925 °C (1700 °F). Remaining structure: ferrite in austenite matrix. Electrolytic: 10% $CrO_3$; 6 V, 5 to 60 s. 500×

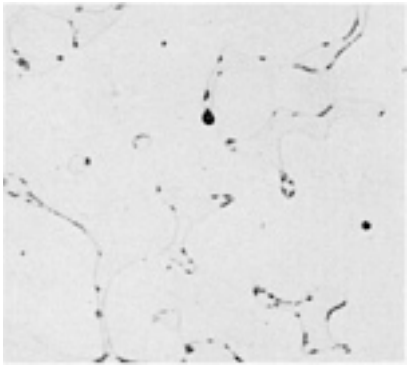

**Fig. 33** CF-8M alloy, solution treated 1 h at 1120 °C (2050 °F) and water quenched, sensitized 1 h at 650 °C (1200 °F) and air cooled. Structure is austenite, with ferrite and carbide precipitates along the austenite-ferrite interface. See also Fig. 34. Glyceregia. 400×

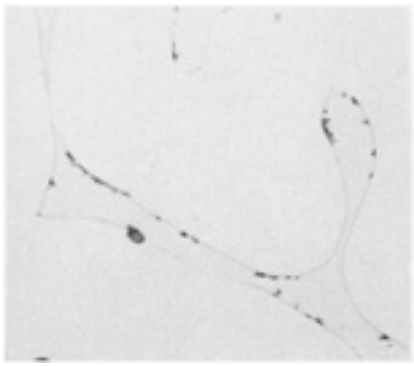

**Fig. 34** Same alloy and processing as Fig. 33. Higher magnification of austenite, ferrite and carbide precipitates at interface. Kalling's reagent. 1000×

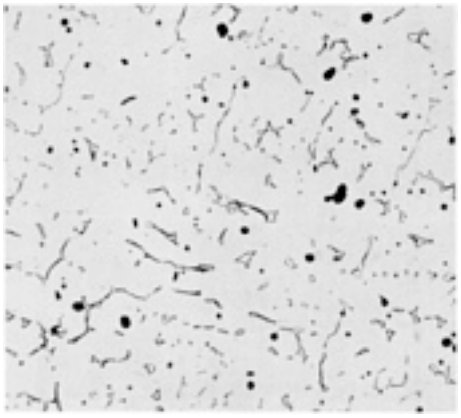

**Fig. 35** CF-16F alloy, a 25-mm (1-in.) bar, as-cast. The structure consists of selenide particles (black), precipitated carbide particles, and fine ferrite islands in a matrix of austenite. Dispersed selenide particles of this type improve the machining characteristics of the steel. Electrolytic: oxalic acid. 100×

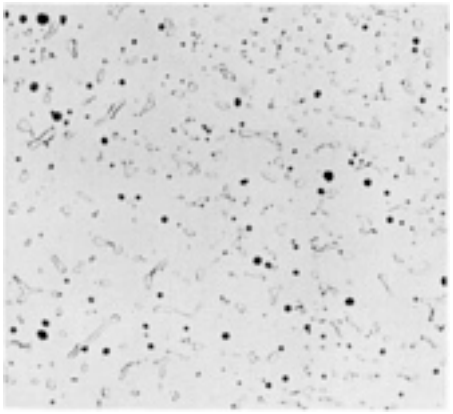

**Fig. 36** Same alloy and bar size as for Fig. 35, but solution treated at 1120 °C (2050 °F) and water quenched. The precipitated carbide particles have dissolved, and the ferrite islands have re-formed. Selenide particles (black) were relatively unaffected by the solution treatment. Electrolytic: oxalic acid. 100×

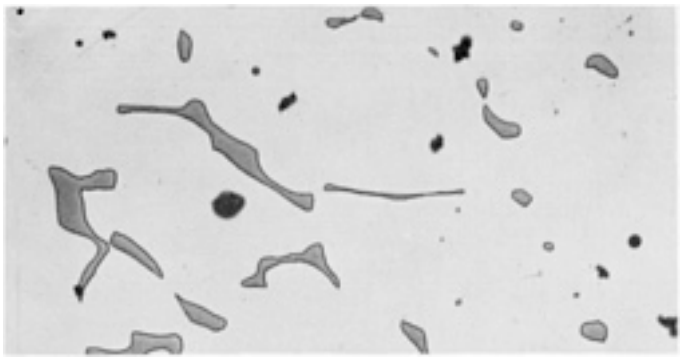

**Fig. 37** CF-16F alloy, solution treated at 1120 °C (2050 °F) and water quenched. The structure consists of selenide particles (dark spots) and islands of ferrite in a matrix of austenite. Electrolytic: 10N KOH. 500×

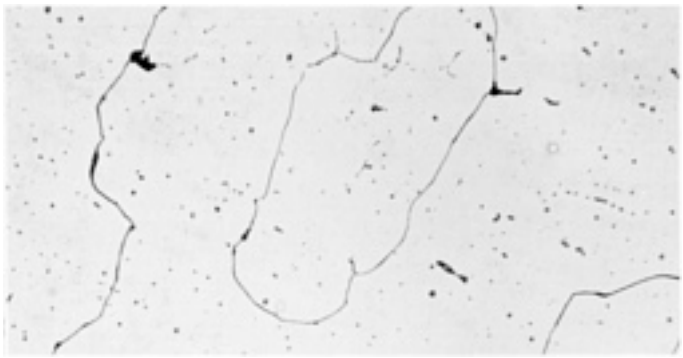

**Fig. 38** CF-20 alloy, a 25-mm (1-in.) bar, as-cast. The structure consists of fine particles of carbide dispersed in a matrix of austenite with precipitated carbide particles at grain boundaries. Oxalic acid. 100×

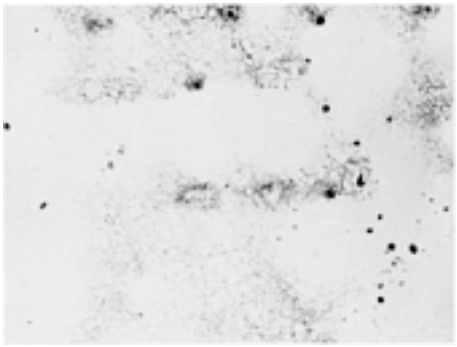

**Fig. 39** CK-20 alloy, 25-mm (1-in.) thick section, as-cast. Primary carbide, precipitated carbide, and globular inclusions (silicate and manganese sulfide) in an austenite matrix. See also Fig. 40. Glyceregia. 200×

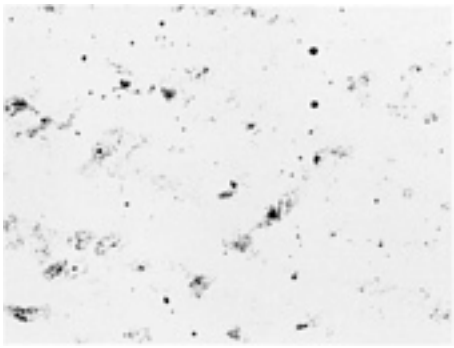

**Fig. 40** Same alloy and section thickness as for Fig. 39, but solution treated at 1120 °C (2050 °F) for 1 h and water quenched. Most precipitated carbide particles have dissolved. Electrolytic: oxalic acid. 100×

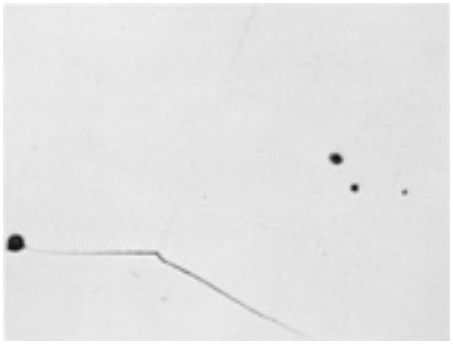

**Fig. 41** CN-7M alloy, 25-mm (1-in.) thick section, as-cast- Precipitated chromium carbide ($M_{33}C_6$) at grain boundaries of the austenite matrix. Black dots are inclusions. See also Fig. 42. Electrolytic: 10% $CrO_3$; 6 V, 5 to 60 s. 500×

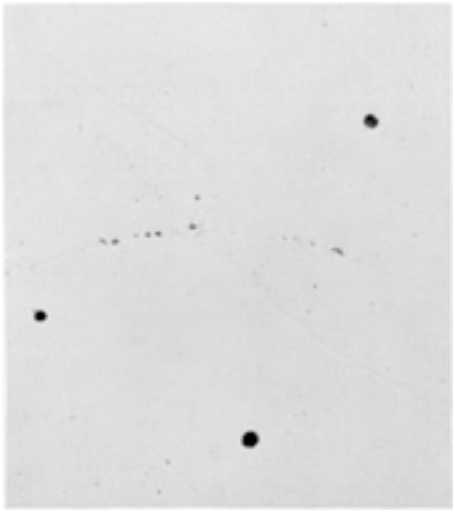

**Fig. 42** Same alloy and section thickness as for Fig. 41, but solution treated 1 h at 1120 °C (2050 °F) and water quenched. Structure shows traces of carbide at grain boundaries of the austenite matrix; black dots are inclusions. Electrolytic: 10% $CrO_3$; 6 V, 5 to 60 s. 500×

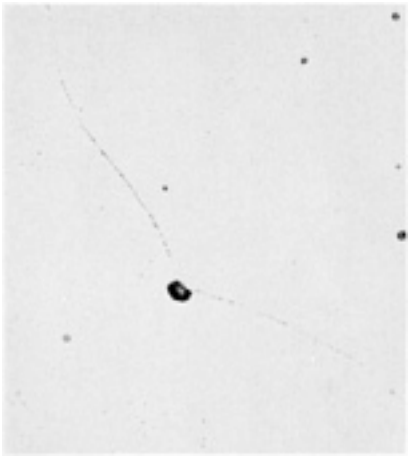

**Fig. 43** CN-7M alloy, solution treated 1 h at 1175 °C (2150 °F) and water quenched. Structure consists of austenite with dispersed inclusions. See also Fig. 44. Electrolytic: oxalic acid. 400×

**Fig. 44** Same alloy and processing as Fig. 43. Higher magnification of dispersed inclusions in austenite matrix. Electrolytic: oxalic acid. 1000×

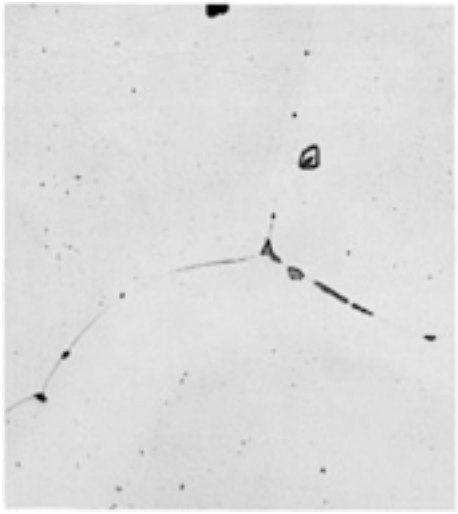

**Fig. 45** CN-7M alloy, 75-mm (3-in.) thick section, as-cast. The structure consists of $M_{23}C_6$ carbides (predominantly, chromium carbide) precipitated at the grain boundaries of the austenite matrix. See also Fig. 46. Electrolytic: oxalic acid. 500×

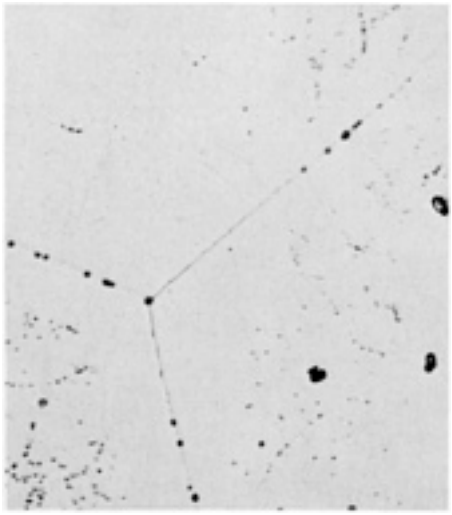

**Fig. 46** Same alloy and section thickness as for Fig. 45, but solution treated at 1120 °C (2050 °F) for 1 h and water quenched. Small discrete chromium carbide particles at grain boundaries of the etch-pitted austenite matrix. Electrolytic: oxalic acid. 500×

**Fig. 47** 440C stainless (Fe-17Cr-0.5.Mo-1.0C), investment cast in a 5 mm (0. 19 in.) section and annealed. Dendritic structure with interdendritic carbide network. See also Fig. 48. Vilella's reagent. 500×

**Fig. 48** Same alloy and processing as Fig. 47. Higher magnification view of Fig. 47, showing interdendritic carbide particles and very fine carbide particles in the matrix. Vilella's reagent. 1000×



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