Case Hardening Steel: Metallographic Techniques and Microstructures

<Previous section in this article

Atlas of Microstructures for Case Hardening Steel

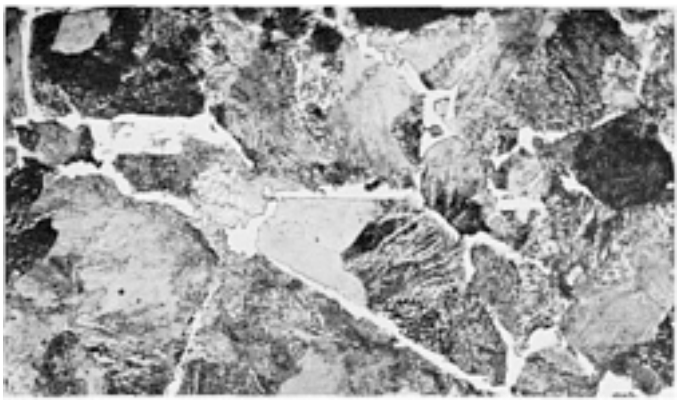

Fig. 1

Fig. 2

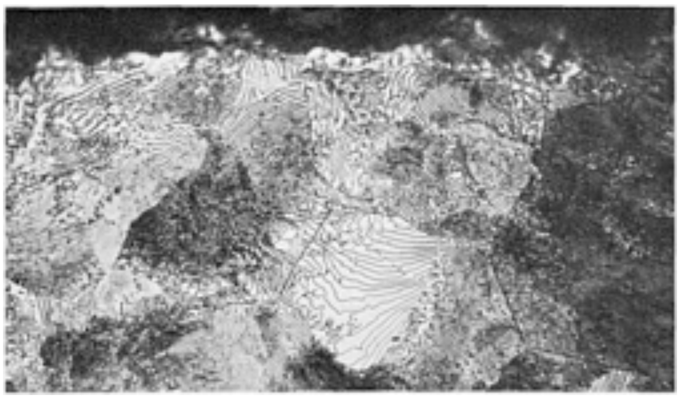

Fig. 3

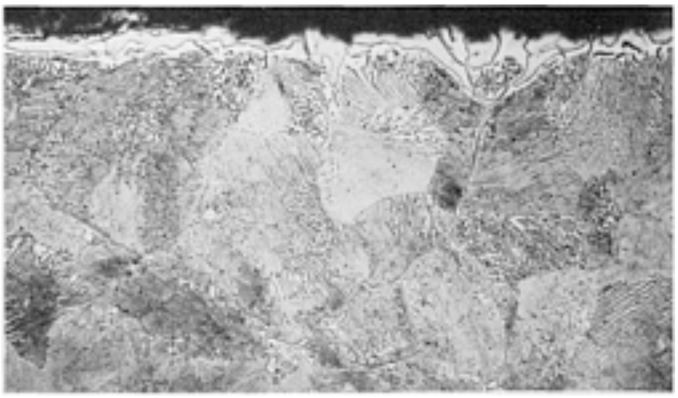

Fig. 4

1018 steel, gas carburized at 925 °C (1700 °F) for different lengths of time to different surface carbon contents. Fig. 1: carburized 2 h; surface carbon content is 0.60 to 0.70%. Structure is ferrite (light), outlining prior austenite grain boundaries, and pearlite. Fig. 2: carburized 4 h. Surface (0.70 to 0.80% C) is pearlitic; below surface, same structure as Fig. 1. Fig. 3: carburized 6 h, with a surface carbon content of 0.90 to 1.00%. A thin film of carbide outlines prior austenite grainboundaries; matrix is pearlite. Fig. 4: carburized 16 h. Surface (1.00 to 1.10% C) is carbide; below the surface, structure is identical to Fig. 3. All etched in 1% nital. 500×

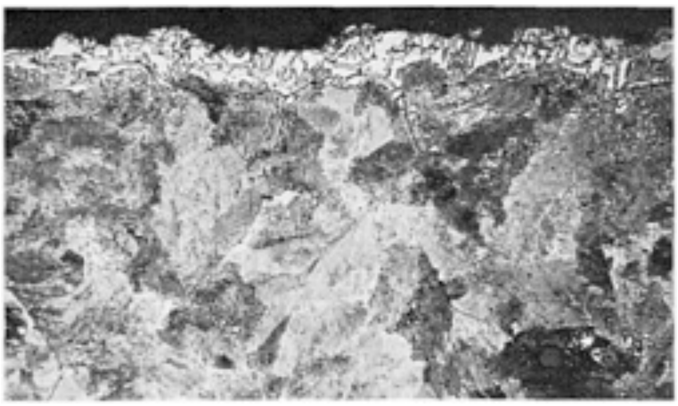

Fig. 5

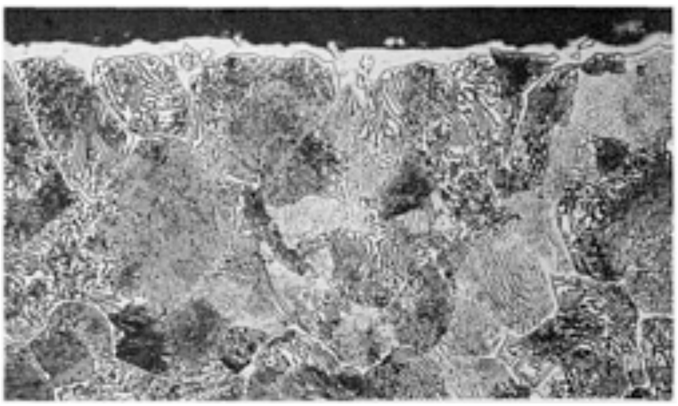

Fig. 6

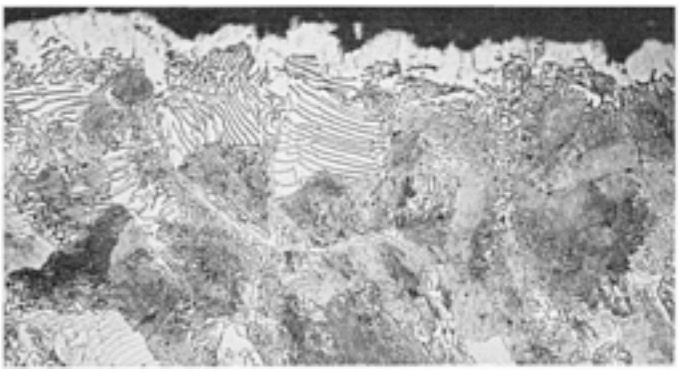

Fig. 7

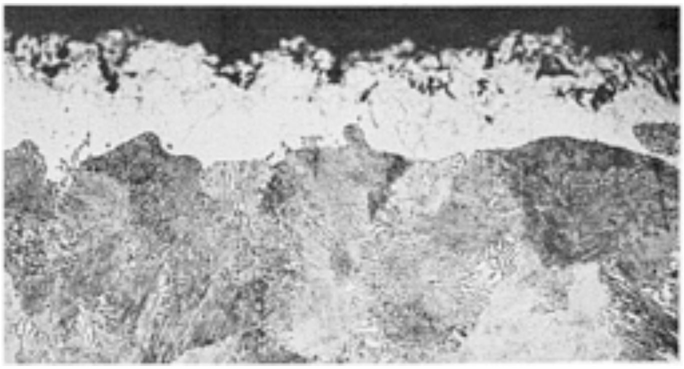

Fig. 8

Same steel as Fig. 1, 2, 3, and 4. Fig. 5: gas carburized 18 h and cooled in the furnace vestibule. A partially separated layer of carbide (approximately 0.90% C) covers the pearlitic matrix. Fig. 6: gas carburized 12 h. Carbide (approximately 1.10% C) on surface; a film of carbide outlines prior austenite grain boundaries in the pearlite matrix. Fig. 7: gas carburized 5 h in a furnace with an air leak, furnace cooled to 535 °C (1000 °F), then air cooled to room temperature. A thin decarburized layer (ferrite) caused by the air leak covers the surface; below the surface, the structure is pearlite and carbide in prior-austenite grain boundaries. Fig. 8: processed under same conditions as Fig. 7, but the air leak was more severe. The decarburized surface layer is thicker. Carbon has diffused from grain boundaries in the pearlite matrix. All etched in 1% nital. 500×

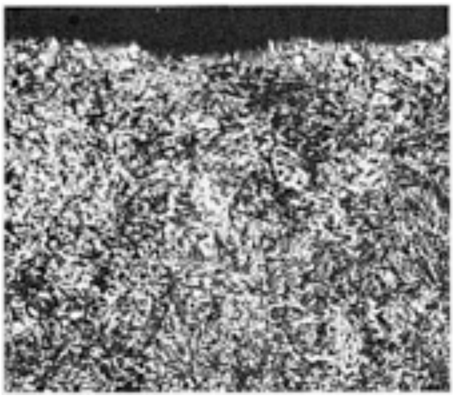

Fig. 9

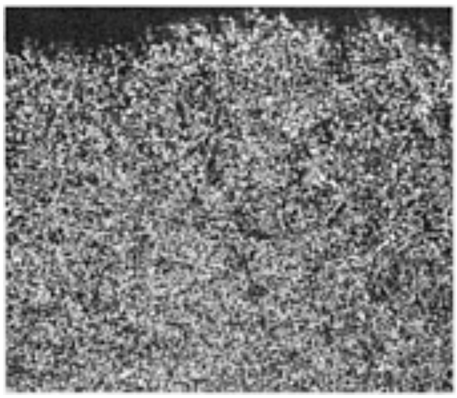

Fig. 10

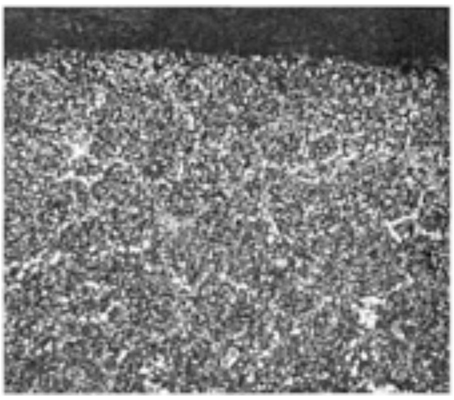

Fig. 11

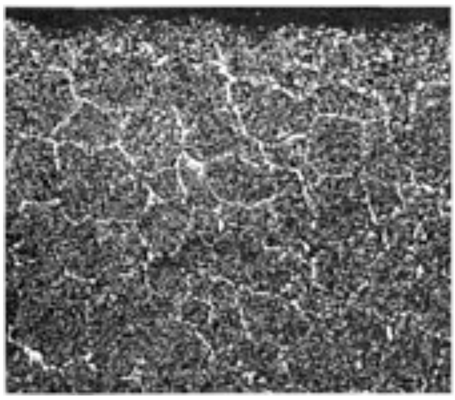

Fig. 12

9310 steel, gas carburized 4 h at 925 to 940 °C (1700 to 1725 °F), furnace cooled, austenitized at 815 to 830 °C (1500 to 1525 °F), oil quenched, and tempered 4 h at 150 °C (300 °F). Specimens have different surface carbon contents because of variations in the carbon potential of the furnace atmosphere. Fig. 9: case carbon content is 0.60%. Fig. 10: case is 0.85% C. Fig. 11: case is 0.95% C. Fig. 12: case is 1.05% C. All etched in 2% nital. 500×

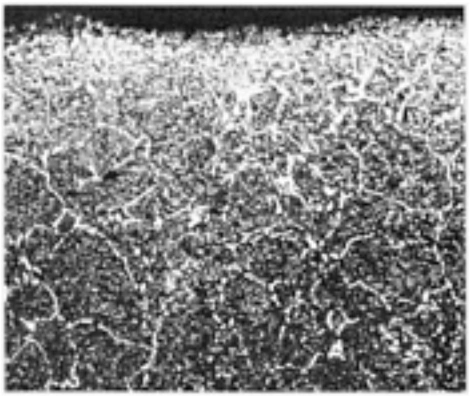

Fig. 13

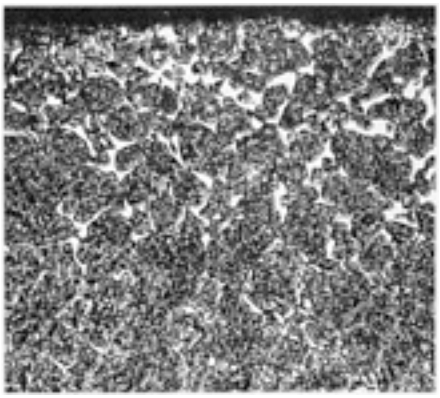

Fig. 14

Same alloy and processing as Fig. 9, 10, 11, and 12. Fig. 13: case carbon content of 1.10%. Fig. 14: case carbon content of 1.20%. Variations in the carbon potential of the furnace atmosphere produced the different carbon contents. Both etched in 2% nital. 500×

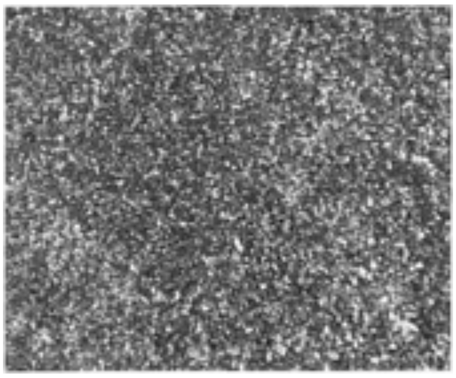

Fig. 15

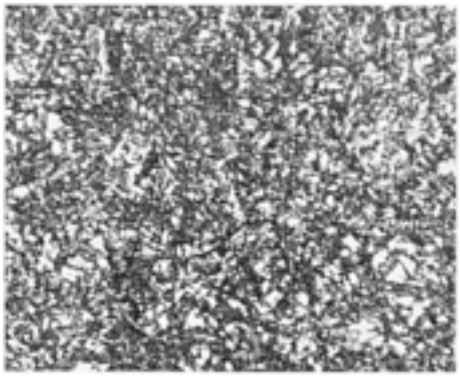

Fig. 16

4620 steel, gas carburized. Fig. 15: carburized 8 h at 940 °C (1725 °F), austenitized at 820 °C (1510 °F), oil quenched, tempered 1 h at 180 °C (360 °F), and retempered 2 h at 260 °C (500 °F). Tempered martensite, lower bainite, and carbide. Fig. 16: same as Fig. 15, but retempered 2 h at 230 °C (450 °F). Structure is tempered martensite, lower bainite, dispersed carbide, and 10% retained austenite (by x-ray). Both etched in nital. 1000×

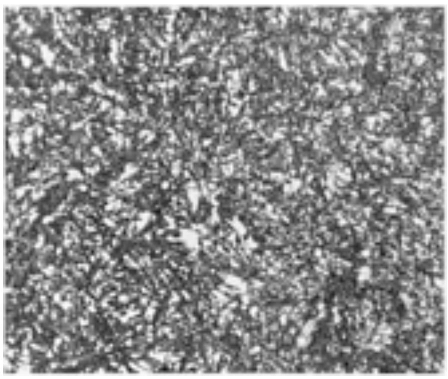

Fig. 17

Fig. 18

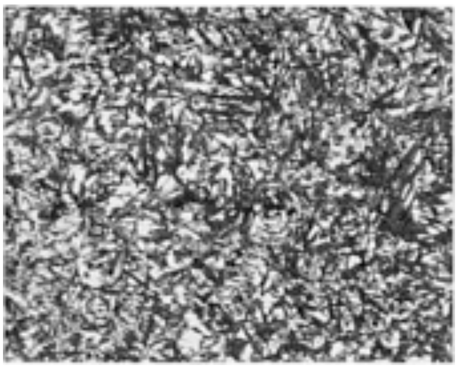

Fig. 19

Fig. 20

4620 steel, gas carburized at 100% carbon potential. Fig. 17: some as Fig. 15 and 16, but retempered 2 h at 220 °C (425 °F). Structure (0.95% C) is tempered martensite, lower bainite, and carbide, with 20% retained austenite by x-ray. Fig. 18: carburized 4 h at 940 °C (1725 °F), oil quenched, and tempered 1 h at 180 °C (360 °F). Microstructure (0.90% C) is tempered martensite and 35% retained austenite (by x-ray). Fig. 19: carburized 8 h at 940 °C (1725 °F), oil quenched, heated 30 min to 820 °C (1510 °F), oil quenched, and tempered 20 min at 95 °C (200 °F). Structure (0.95% C): tempered martensite and 40% (by x-ray) retained austenite. Fig. 20: same carburization as Fig. 19, oil quenched and tempered 1 h at 180 °C (360 °F). Microstructure consists of tempered martensite and 45% retained austenite (by x-ray). All etched in nital. 1000×

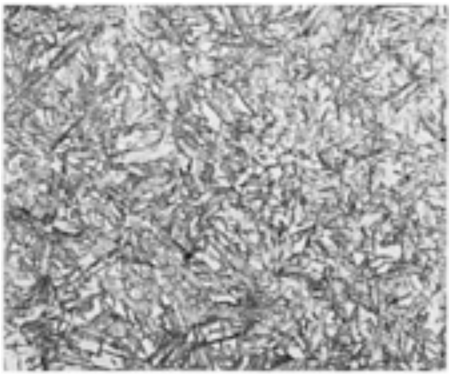

Fig. 21 4620 steel, gas carburized 4 h at 955 °C (1750 °F), austenitized 30 min at 820 °C (1510 °F), and oil quenched. Structure is martensite and 25% (by x-ray) retained austenite. Nital. 1000×

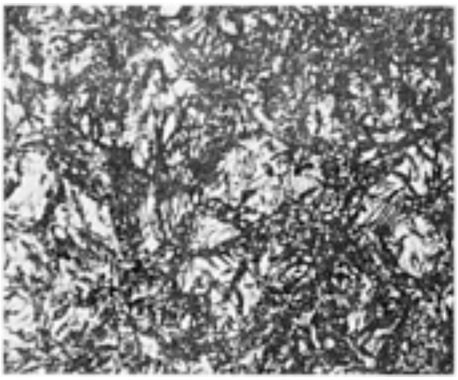

Fig. 22

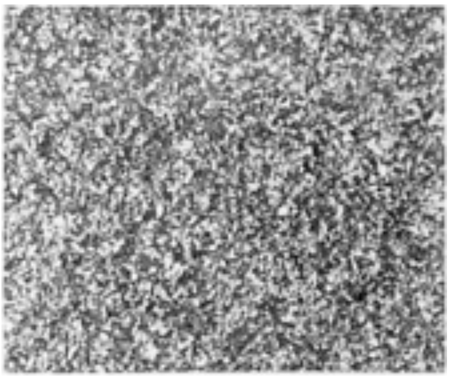

Fig. 23

3310 steel, gas carburized 16 h at 1.20% carbon potential at 955 °C (1750 °F), oil quenched, heated to 795 °C (1460 °F), oil quenched, and tempered 1 h at 180 °C (360 °F). Fig. 22: structure (1.00% C) is tempered martensite with 30% retained austenite (by x-ray). Fig. 23: same as Fig. 22, but tempered 13 h at 595 °C (1100 °F) before being heated for hardening. Structure (1.00% C): tempered martensite, undissolved carbides, and 20% (by x-ray) retained austenite. Both etched in nital. 1000×

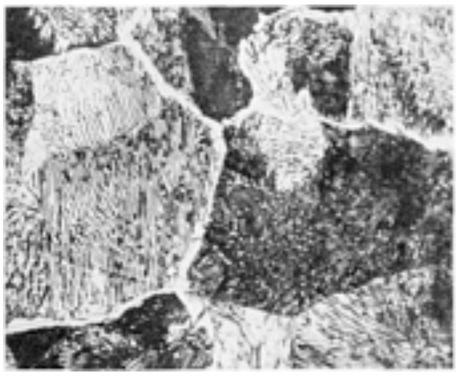

Fig. 24

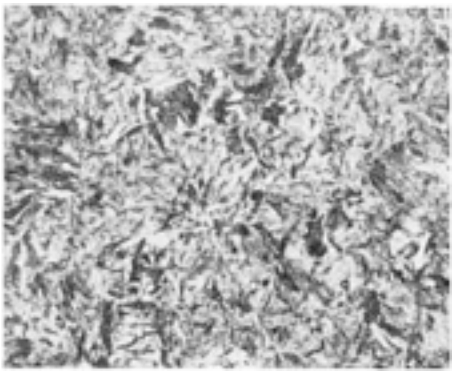

Fig. 25

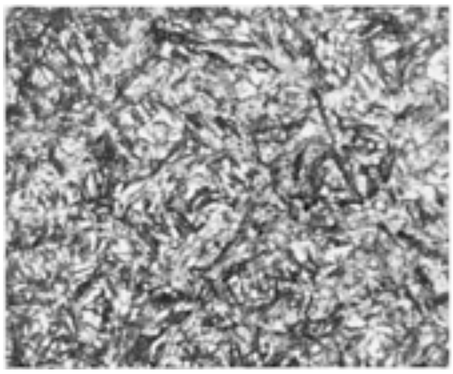

Fig. 26

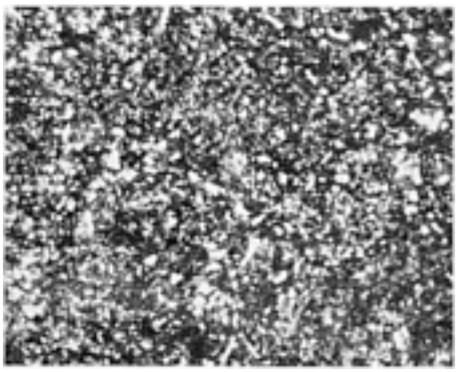

Fig. 27

8720 hot-rolled steel, gas carburized at 1.35% carbon potential for 9 h at 925 °C (1700 °F) and diffused 2 h at the same temperature. Fig. 24: specimen was slowly cooled in the furnace. Microstructure is a light carbide network in a matrix of pearlite. Fig. 25: austenitized at 0.90% carbon potential for 1 h at 815 °C (1500 °F), oil quenched, and tempered 1 h at 190 °C (375 °F). Structure is relatively low-carbon tempered martensite. Fig. 26; same austenitizing and tempering as Fig. 25. Structure is globular carbide and retained austenite in a matrix of tempered martensite with a higher carbon content than Fig. 25. Fig. 27: austenitized at 1.35% carbon potential for 1 h at 815 °C (1500 °F), oil quenched, and tempered 1 h at 1 90 °C (375 °F). Carbide (light network, globular particles) in a tempered martensite matrix; retained austenite is not visible. All etched in 5% nital. 1000×

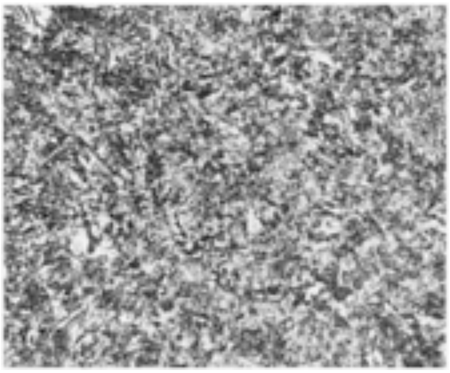

Fig. 28

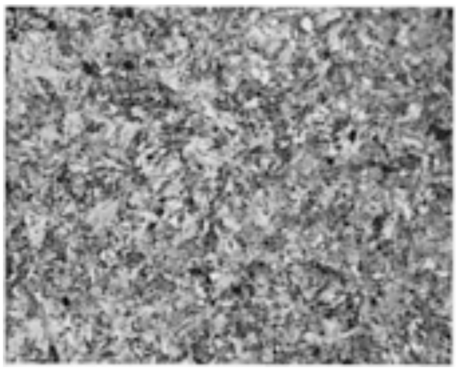

Fig. 29

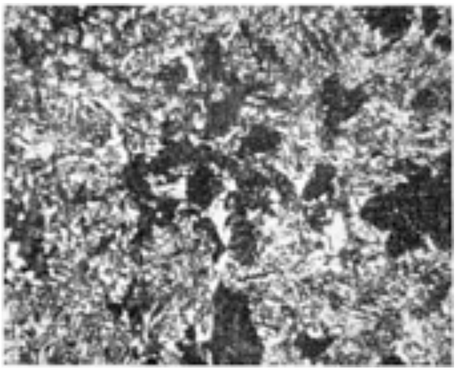

Fig. 30

Fig. 31

8720 hot-rolled steel, gas carburized at 1.35% carbon potential for 9 h at 925 °C (1700 °F). Fig. 28: specimen was austenitized 1 h at 815 °C (1500 °F), oil quenched, and tempered 1 h at 260 °C (500 °F).

A small amount of retained austenite (white areas) is visible in a matrix of overtempered martensite. Fig. 29: specimen was austenitized and quenched same as Fig. 28, then tempered 1 h at 120 °C (250 °F). Tempered martensite structure shows the effects of undertempering. Fig. 30: specimen was austenitized same as Fig. 28 and 29, rapidly air cooled, and tempered 1 h at 190 °C (375 °F). Structure consists of fine pearlite (dark) in a matrix of bainite. Fig. 31: same processing as Fig. 29, but oil quenched. This specimen was overheated during grinding, then rapidly cooled. As a result, the structure consists of retained austenite (white) and untempered martensite. All etched in 5% nital. 1000×

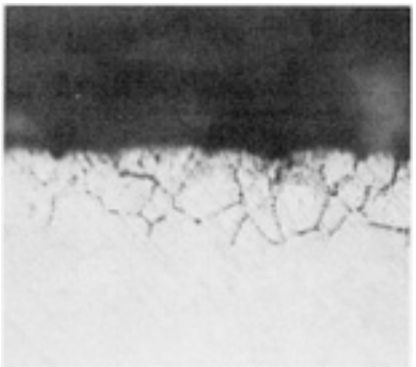

Fig. 32 8620 steel, gas carburized at 955 °C (1750 °F). Specimen shows grain-boundary oxidation to a depth of approximately 0.02 mm (0.0009 in.). 1% nital. 750×

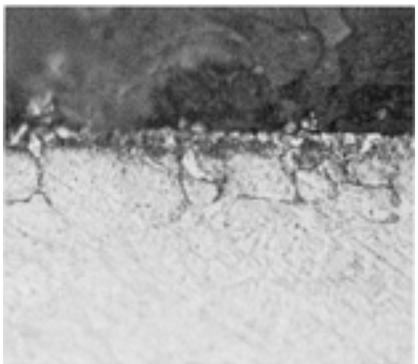

Fig. 33 4118 steel, gas carburized at 955 °C (1750 °F). Grain-boundary oxidation to a depth of approximately 0.02 mm (0.0009 in.). As polished. 750×

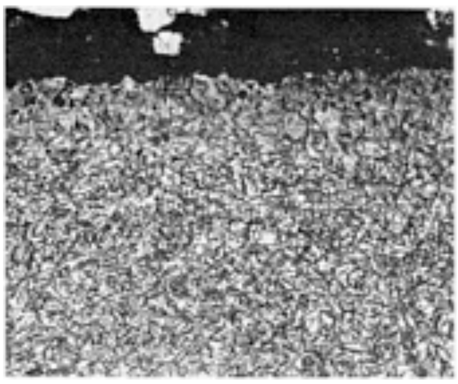

Fig. 34 8620H steel, gas carburized 18 h at 925 °C (1700 °F), reheated to 840 °C (1540 °F) and held 40 min, oil quenched, and tempered 1 h at 175 °C (350 °F). Grain-boundary oxides near the surface and carbide particles and retained austenite in a tempered martensite matrix. 4% picral. 500×

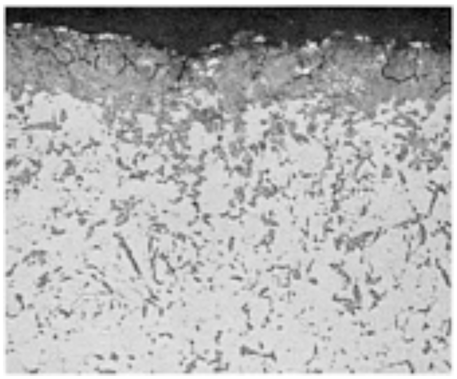

Fig. 35 8822H steel, gas carburized 15 h at 925 °C (1700 °F), reheated to 840 °C (1540 °F) and held 40 min, oil quenched, and tempered 2 h at 150 °C (300 °F). Structure is similar to Fig. 34, but a bainite-pearlite mixture near the surface is visible because of the lighter etching. 2% picral. 500×

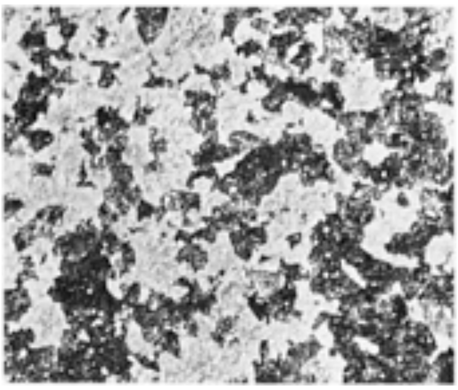

Fig. 36 4320 steel, gas carburized 8 h at 940 °C (1725 °F), reheated to 830 °C (1525 °F) and held 1 h, slack quenched by end quenching the cylinder in oil, and tempered 1 h at 180 °C (360 °F). Structure is 50% pearlite (dark) and undissolved particles of alloy carbide in a matrix of tempered martensite. Nital. 1000×

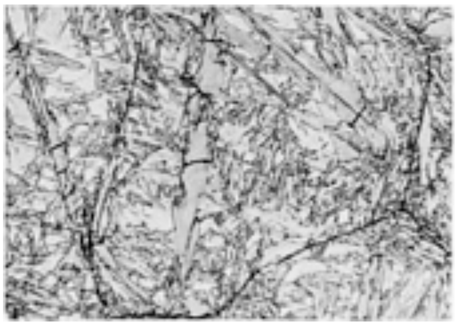

Fig. 37 3310H steel, gas carburized 12 h at 925 °C (1700 °F), furnace cooled to 535 °C (1000 °F), and air cooled. The structure consists of large plates of martensite that show microcracks in a matrix of retained austenite. 4% picral with 0.01% HCl. 500×

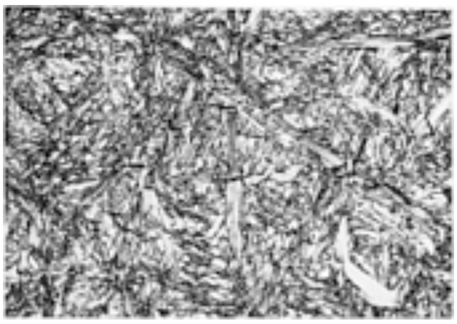

Fig. 38 Same as Fig. 37, except more heavily etched. Details of the structure are improved, but the

microcracks in the martensite plates have been obscured by the darker etch. 4% picral with 0.01% HCl. 500×

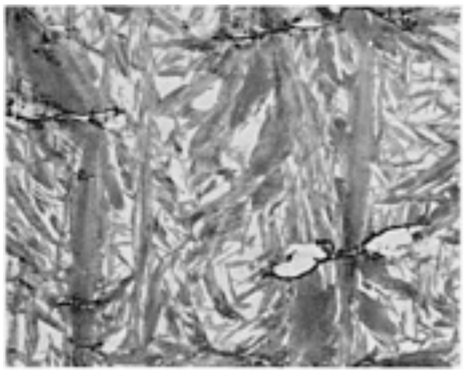

Fig. 39 8620 steel, gas carburized 11 h at 925 °C (1700 °F), furnace cooled to 845 °C (1550 °F), oil quenched, and tempered 2 h at 195 °C (380 °F). Specimen was subjected to maximum compressive stress of 4135 MPa (600 ksi) for 11.4 million cycles in a contact-fatigue test. "Butterfly" structural alterations developed at microcracks. Picral. 1000×

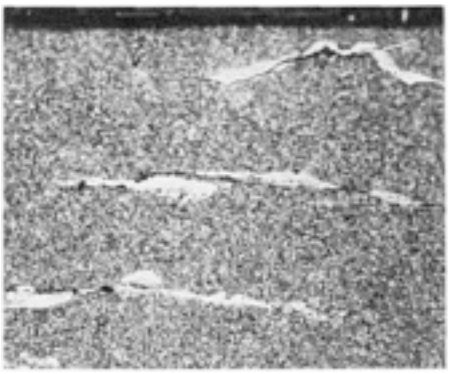

Fig. 40 8822H steel roller for a contact-fatigue test, gas carburized 15 h at 925 °C (1700 °F), furnace cooled, heated to 805 °C (1480 °F) and held 1 h, oil quenched, and tempered 1 h at 175 °C (350 °F). Structural alterations developed at sub-surface cracks. See also Fig. 43. 1% nital. 275×

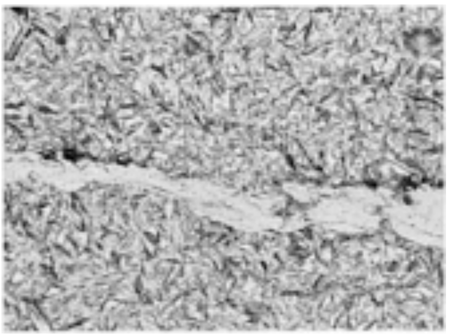

Fig. 41 4620 steel, gas carburized and hardened, showing a microstructural alteration (light gray streak) formed at an Al_2O_3 stringer inclusion. The stress-induced alteration is approximately 0.25 mm (0.01 in.) from the rolling contact surface. Nital. 500×

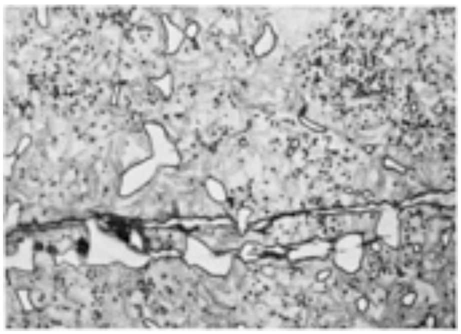

Fig. 42 Gas-carburized 8822H steel roller for a contact-fatigue test, showing structural alterations associated with carbide phase. The roller was carburized, furnace cooled, reheated, oil quenched, and tempered. The structure consists of retained austenite, martensite, and carbide. 4% picral. 1500×

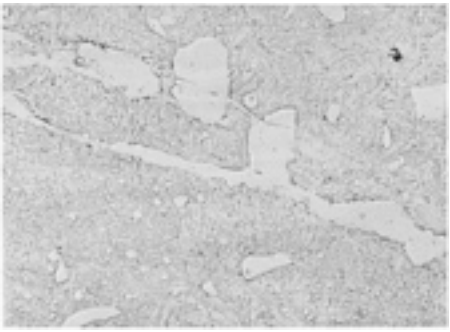

Fig. 43 Replica electron micrograph of the specimen in Fig. 40. These structural alterations form at microcracks just as "butterfly" alterations form at inclusions. 4% picral. 1600×

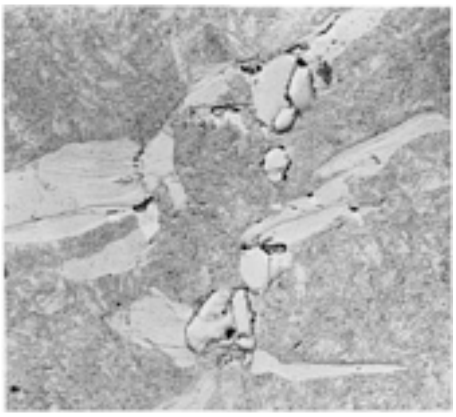

Fig. 44 Replica electron micrograph of a gas-carburized 1039 steel roller for use in contact-fatigue tests. "Butterfly" alterations, which form at inclusions, are approximately 0.12 mm (0.005 in.) from the contact surface and are believed to be oriented in the direction of principal stress. 2% picral. 1950×

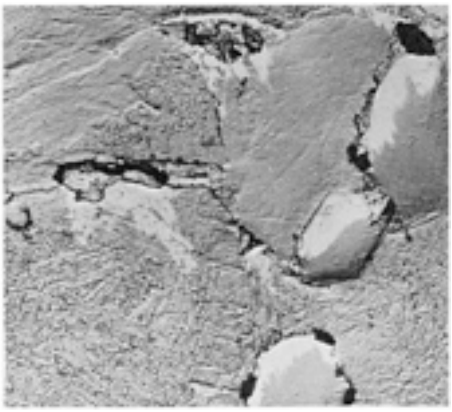

Fig. 45 Same material and heat treating conditions as Fig. 44, but the area of alteration is at a higher magnification, which shows that microcracks surround the altered metal; slip bands in martensite to the left of the lower inclusion are also visible. 2% picral. 7500×

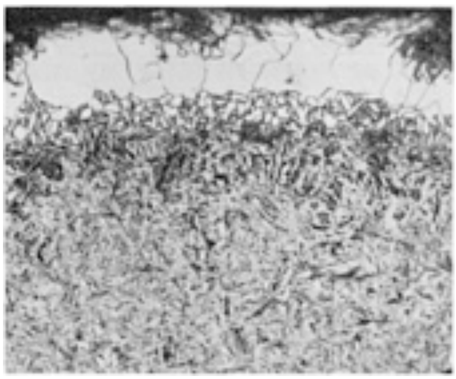

Fig. 46 4118H steel bar, gas carburized 8 h at 925 °C (1700 °F), oil quenched, heated to 845 °C (1550 °F) and held 15 min, oil quenched, and tempered 1 h at 170 °C (340 °F). Completely decarburized surface layer (white), a transition zone of ferrite and low-carbon martensite, and a matrix of tempered martensite and retained austenite. 4% nital. 500×

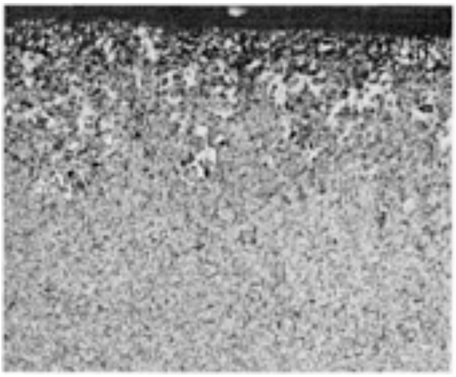

Fig. 47 Same material and heat treating conditions as Fig. 46. Surface is only partially decarburized, because this low-alloy steel specimen previously contained precipitated, intergranular carbide particles. Matrix is same as described in Fig. 46. 4% nital. 100×

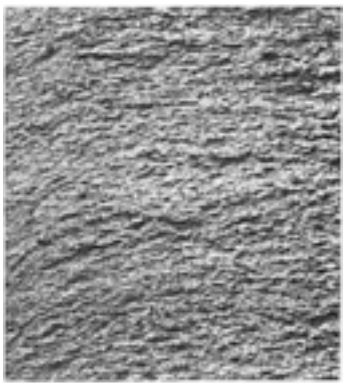

Fig. 48

Fig. 49

Fig. 50

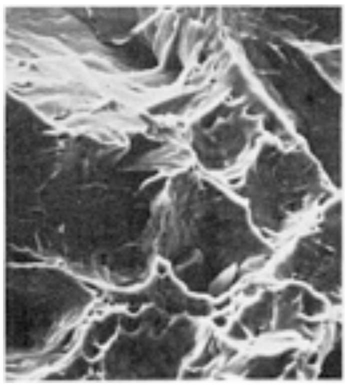

Fig. 51

8620H steel tubing, gas carburized 8 h at 925 °C (1700 °F), hardened, and tempered. Fig. 48: scanning electron micrograph of the fractured carburized case. Compare with Fig. 49, which shows the same specimen at a higher magnification. The structure of the case consists of carbide, retained austenite, and tempered martensite. Fig. 50: scanning electron micrograph of the uncarburized core material (low-carbon martensite). Fig. 51: higher magnification shows that the fractured core material has elongated dimples formed during transgranular rupture. All not polished, not etched. Fig. 48 and 50: 23×; Fig. 49 and 51: 1100×

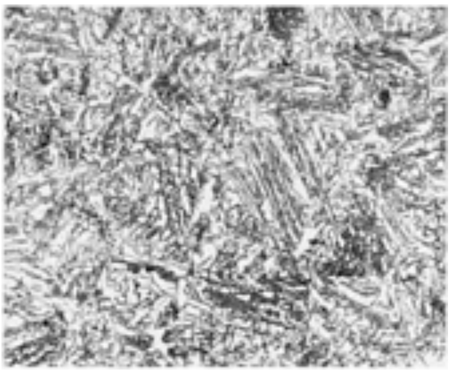

Fig. 52 4620 steel, pack carburized 16 h at 940 °C (1725 °F) and cooled in the pot. Structure contains 1% C and consists of ferrite (light), pearlite (dark), and a trace of carbide envelopes at prior austenite grain boundaries. Nital. 1000×

Fig. 53 3310 steel, pack carburized 16 h at 940 °C (1725 °F) and cooled in the pot. Structure is fine pearlite (dark) and carbide envelopes at prior austenite grain boundaries in a matrix of ferrite and dispersed alloy carbide. Nital. 1000×

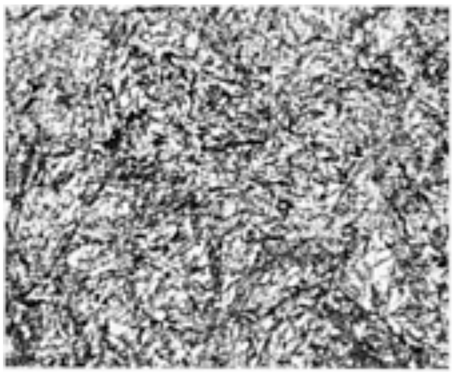

Fig. 54 Same steel and carburizing as Fig. 53, but tempered 13 h at 595 °C (1100 °F), air cooled, heated to 795 °C (1460 °F), oil quenched, and tempered 1 h at 180 °C (360 °F). Structure is tempered martensite, retained austenite (30% by x-ray), and carbide. Nital. 1000×

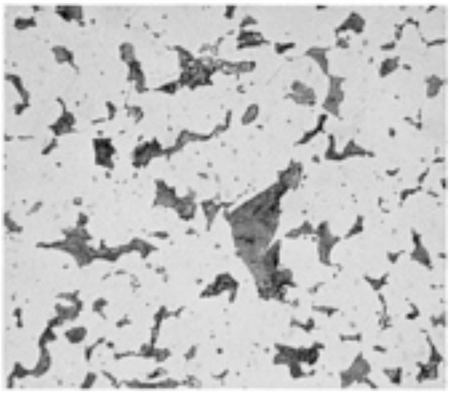

Fig. 55 1018 steel bar, austenitized 2 h at 885 °C (1625 °F), then furnace cooled. The structure before carburizing is patches of pearlite (dark) in a matrix of ferrite. Picral. 200×

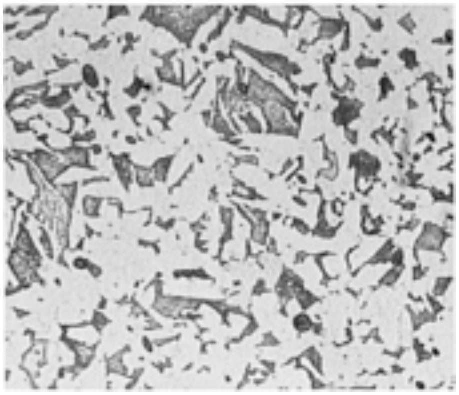

Fig. 56 1117 steel bar, normalized by austenitizing 2 h at 900 °C (1650 °F) and cooled in still air. Ferrite (light) with traces of Widmanstätten ferrite, fine pearlite (dark), and particles of MnS. Picral. 200×

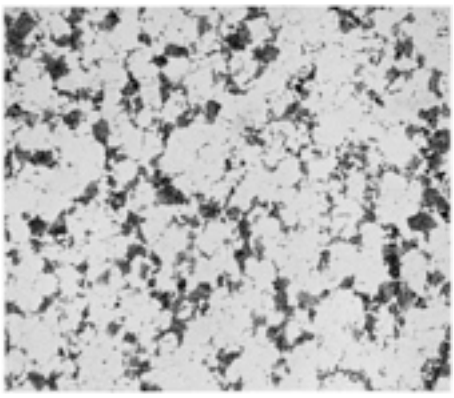

Fig. 57 8617 steel bar, annealed by austenitizing 2 h at 870 °C (1600 °F) and furnace cooled. Fine pearlite (dark) in a ferrite matrix. Magnification is too low for good resolution of the structure. Picral. 200×

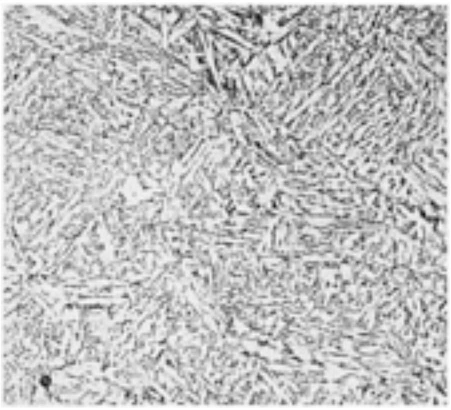

Fig. 58 8620 steel bar, normalized by austenitizing 2 h at 900 °C (1650 °F) and cooled in still air. Structure is a mixture of ferrite and carbide. Cooling was too rapid to produce an annealed structure. Picral. 200×

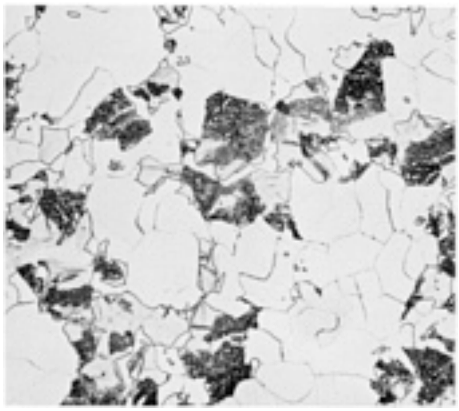

Fig. 59 8822H steel bar austenitized 1 h at 925 °C (1700 °F) and furnace cooled 2 h and 10 min to 540 °C (1000 °F), then air cooled. Structure is pearlite (dark) in matrix of ferrite. 1% nital. 500×

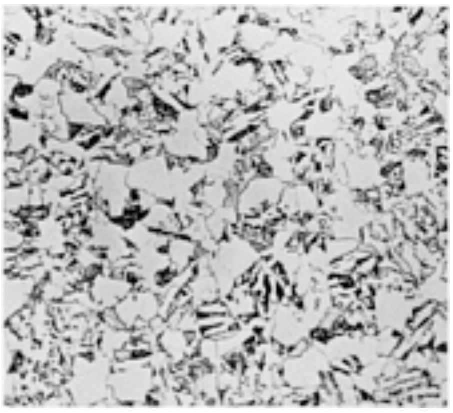

Fig. 60 Same steel and processing as Fig. 59, but cooled in still air. Blocky ferrite (light) and areas of fine ferrite and bainite in a matrix of pearlite. 1% nital. 500×

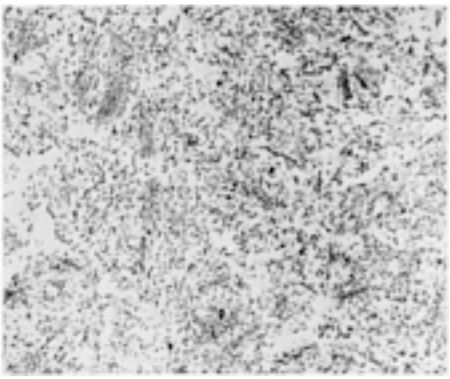

Fig. 61 3310 steel bar, austenitized 4 h at 830 °C (1525 °F), cooled to 620 °C (1150 °F) and held 24 h, and tempered 20 h at 640 °C (1180 °F). Structure consists of fine, dispersed carbide particles in a matrix of ferrite. Picral. 1000×

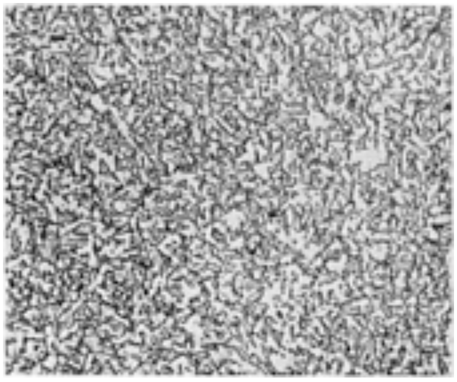

Fig. 62 9310 steel bar, normalized by austenitizing 2 h at 885 °C (1625 °F) and cooled in still air. Structure is scattered carbide particles and unresolved pearlite in a matrix of ferrite (light). Picral. 200×

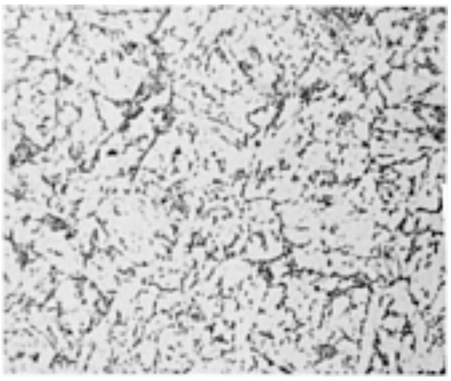

Fig. 63 Same steel and processing as Fig. 62, except cooled slowly in the furnace. Structure consists of scattered carbide particles (dark) in a ferrite matrix (light). 3% nital. 500×

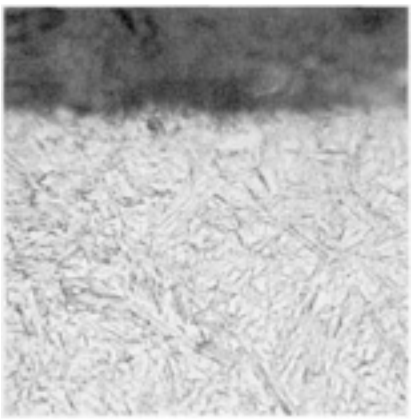

Fig. 64 8620H steel, vacuum carburized 69 min at 980 °C (1800 °F), diffused 78 min, cooled to 845 °C (1550 °F), equalized 30 min, and quenched in oil at 40 °C (1100 °F). Microstructure consists of martensite needles and retained austenite. Case depth is 1.8 mm (0.070 in.). Nital. 500×

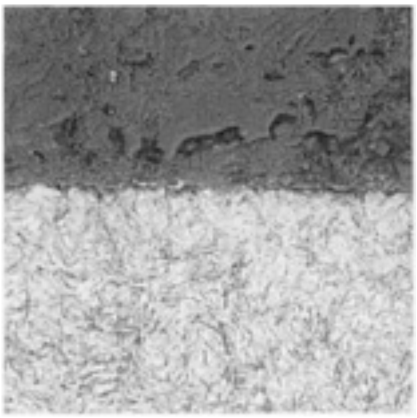

Fig. 65 Same steel as Fig. 64, ion carburized 40 min, diffused 100 min at 980 °C (1800 °F), cooled to 845 °C (1550 °F), equalized 30 min, then quenched in oil at 40 °C (100 °F). Structure is martensite, with a small amount of retained austenite. Case depth is 1.8 mm (0.070 in.). Nital. 500×

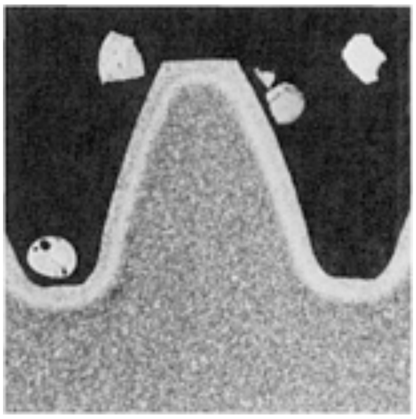

Fig. 66 12H2N4A steel gear [0.16% C(max), 0.6% Mn(max), 0.37% Si(max), 0.03% P(max), 0.025% S(max), 1.65% Cr(max), 3.65% Ni(max)], ion carburized and diffused at 920 °C (1690 °F), austenitized at 830 °C (1525 °F), oil quenched, and tempered at 150 °C (300 °F). Uniform case depth on a 40-tooth gear. See also Fig. 67. Nital. 6×

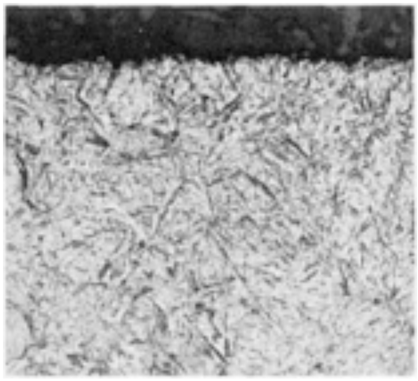

Fig. 67 Microstructure of ion-carburized gear in Fig. 66. The structure is uniformly distributed tempered martensite, with no evidence of carbide or retained austenite. Nital. 200×

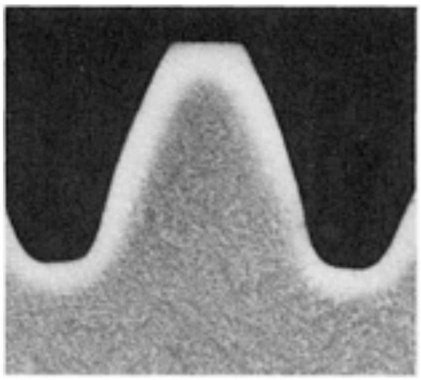

Fig. 68 Same steel and processing as Fig. 67. Uniform case depth on a 40-tooth gear. Effective case depth is 0.8 to 1.0 mm (0.03 to 0.04 in.). See Fig. 69 for microstructure. Nital. 6×

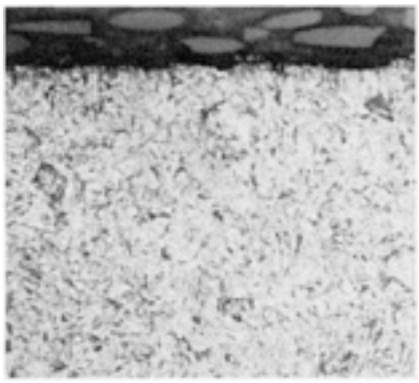

Fig. 69 Microstructure of ion-carburized gear in Fig. 68. Tempered martensite. There is no evidence of carbide or retained austenite. Nital. 200×

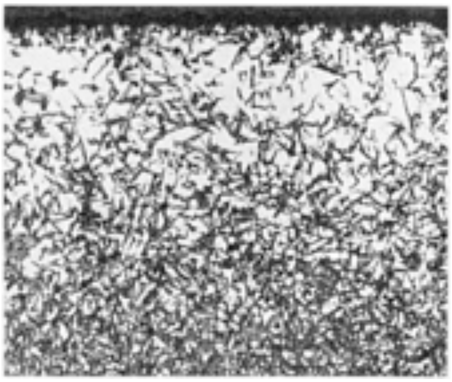

Fig. 70 8617 steel, carbonitrided 4 h at 845 °C (1550 °F) in 8% ammonia, 8% propane, and remainder endothermic gas; oil quenched; and tempered 1.5 h at 150 °C (300 °F). Structure is

tempered martensite (dark) and retained austenite. 3% nital. 200×

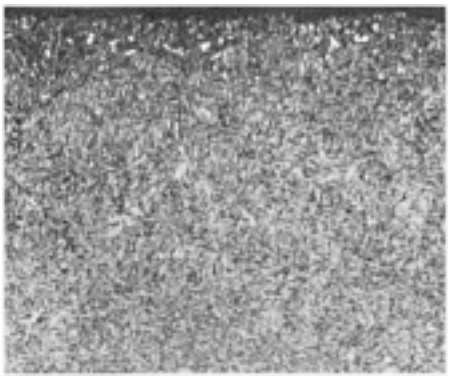

Fig. 71 8617 steel bar, carbonitrided and tempered same as Fig. 70, except held 2 h at -75 °C (-100 °F) between quench and tempering. The structure is scattered carbide in a matrix of tempered martensite. Most of the retained austenite was transformed during low-temperature hold. 3% nital. 200×

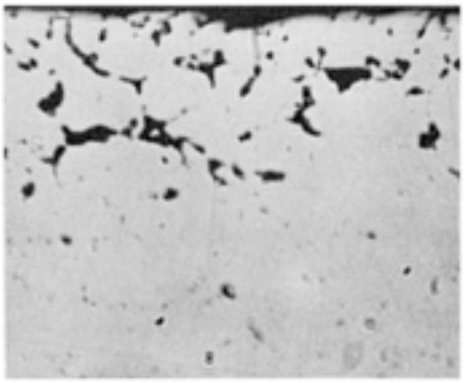

Fig. 72 1012 modified (0.03% Ni, 0.30% Cr) steel, cold-rolled strip carbonitrided 1 h at 845 °C (1550 °F) and oil quenched. Specimen shows networks of subsurface grain-boundary voids. See also Fig. 73 and 74. As-polished. 1000×

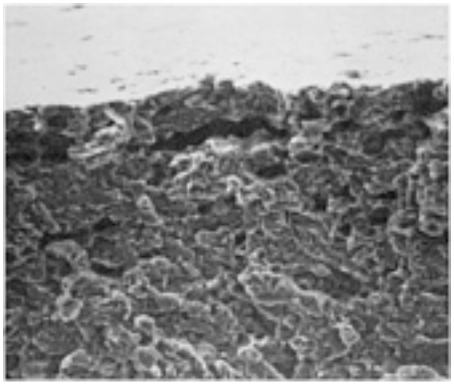

Fig. 73 Scanning electron micrograph of a fracture surface in the same steel as Fig. 72. Void formation appears to involve the formation of diatomic gas molecules (probably nitrogen) at prior austenite grain boundaries. Not polished, not etched. 750×

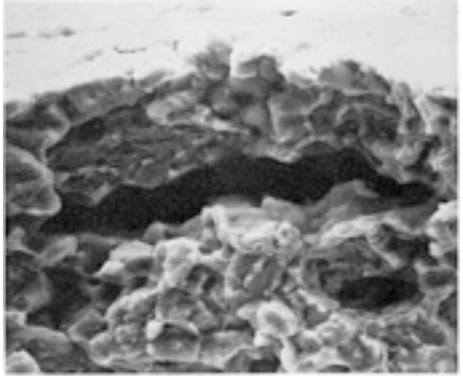

Fig. 74 Same as Fig. 73, but at higher magnification. The formation of grain-boundary voids is promoted by carbonitriding above 855 °C (1575 °F) and by total carbon and nitrogen potentials above 1%. Not polished, not etched. 2000×

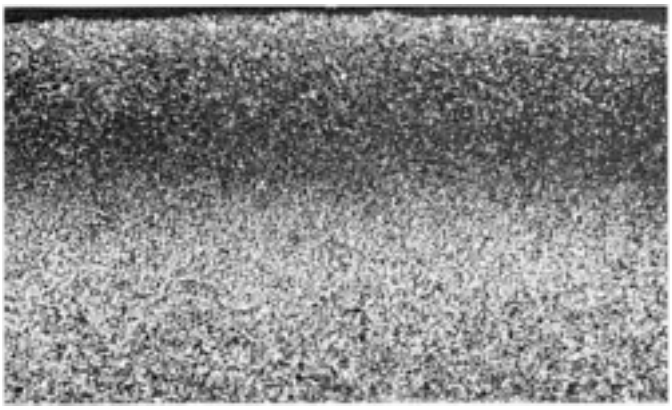

Fig. 75 1018 steel bar, carbonitrided 4 h at 845 °C (1550 °F), oil quenched, and stabilized by sub-zero treatment. The structure contains martensite and carbide particles, and a small amount of retained austenite. Additional carbonitrided materials and their representative microstructures can be found in Fig. 70, 71, 72, 73, 74, 76, 77, 78, and 79. Nital. 100×

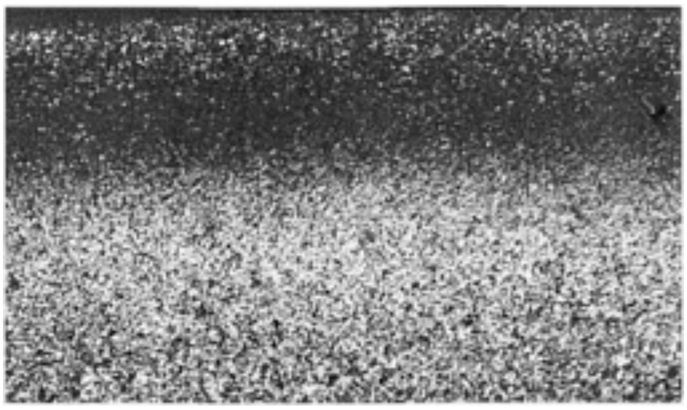

Fig. 76 8620 steel bar, processed under the same conditions as Fig. 75. Structure is the same as Fig. 75, but the appearance of the carbonitrided case differs because of the alloy content of 8620 steel. Nital. 100×

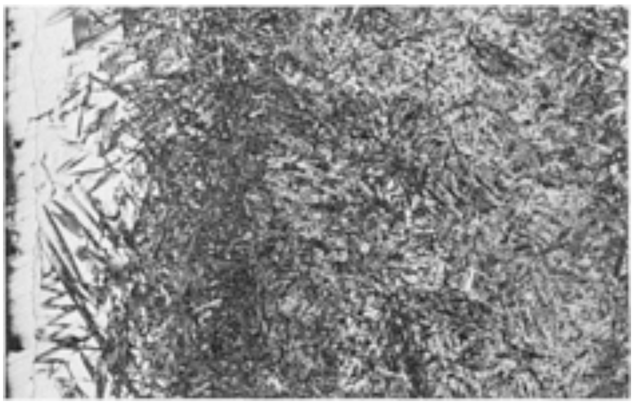

Fig. 77 1020 steel, carbonitrided and oil quenched. The effects on microstructure of too high a carbon potential: a white layer of cementite in the case (left), retained austenite interlaced with martensite needles, and a martensite matrix (right). Nital. 500×

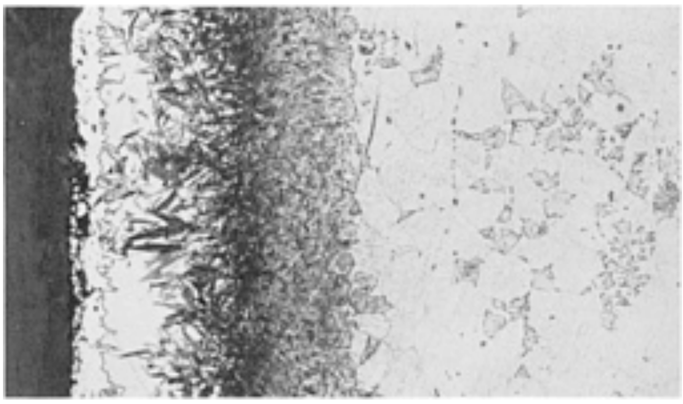

Fig. 78 1010 steel, carbonitrided at 790 °C (1450 °F) and oil quenched. The case (left) is high carbon, with a structure similar to that in Fig. 77; the core (right) is predominantly ferrite. Nital. 200×

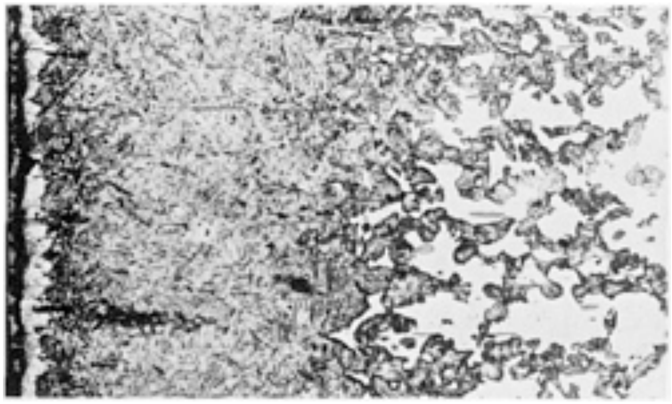

Fig. 79 1117 steel, carbonitrided and oil quenched. A surface layer of decarburized ferrite (left) is superimposed on a normal case structure of martensite. The core (right) contains patches of ferrite (white). Nital. 200×

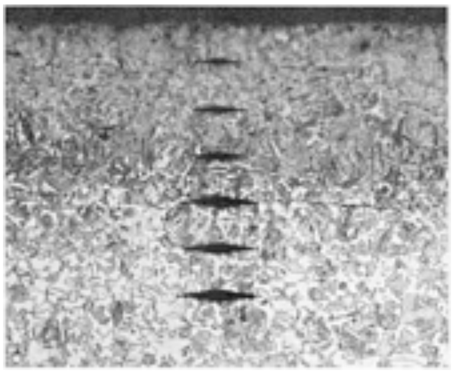

Fig. 80 1020 steel, cyanided 1 h in a salt bath at 845 °C (1550 °F) and water quenched. The case (top) is martensite with some carbide. The core is ferrite. Microhardness indents 0.08 mm (0.003 in.) apart illustrate hardness difference between case (61 HRC) and core (25.5 HRC). 2% nital. 100×

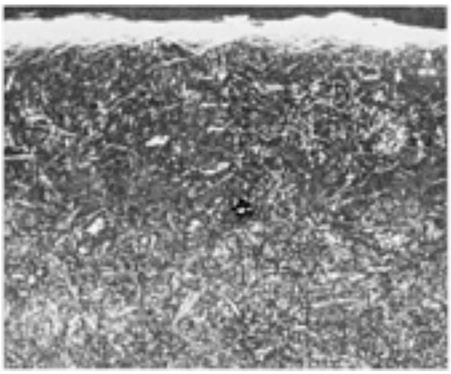

Fig. 81 AMS 6470 steel with 0.15 to 0.35% Pb added, oil quenched from 900 °C (1650 °F), tempered 2 h at 605 °C (1125 °F), surface activated in manganese phosphate, and gas nitrided 30 h at 525 °C (975 °F). Structure is a white layer of Fe_2N and a matrix of tempered martensite. 2% nital. 400×

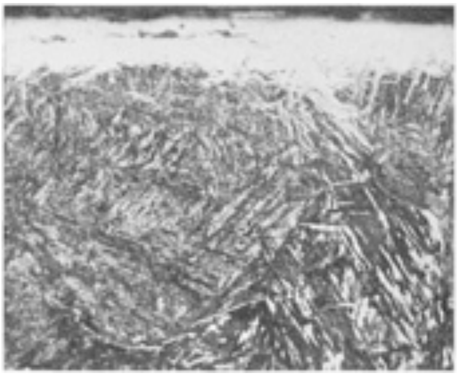

Fig. 82 Same material and heat treating conditions as described in Fig. 81, except nitrided 36 h. The depth of the nitride layer has increased, and platelets of iron nitride can be seen in the case. 2% nital. 400×

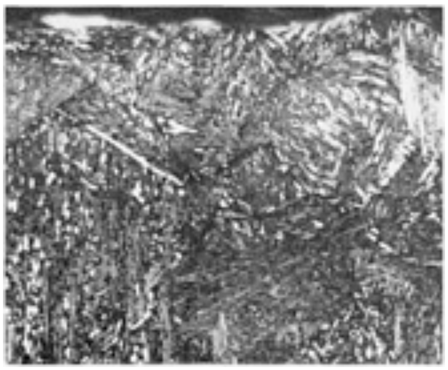

Fig. 83 Same steel and prenitriding conditions as Fig. 81, but double stage nitrided: 5 h at 525 °C (975 °F), followed by 20 h at 565 °C (1050 °F). The white nitride layer shown in Fig. 81 and 82 has been eliminated by dissociation in the second stage of nitriding. 2% nital. 400×

Fig. 84 Same steel and processing as Fig. 81, but the surface was heavily burnished and not chemically activated before nitriding. The lack of surface activation retarded diffusion into the case. 2% nital. 400×

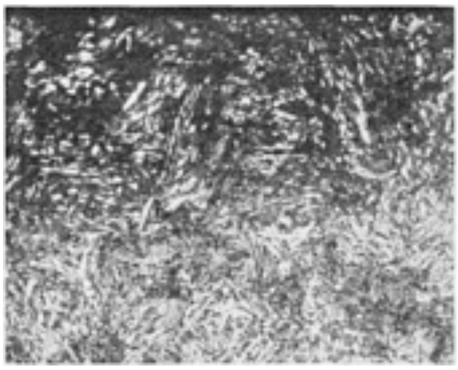

Fig. 85 Same steel and processing as Fig. 81, except slack quenched and ground heavily before nitriding. Because the surface was not chemically activated before nitriding, nitrogen diffusion was retarded. 2% nital. 400×

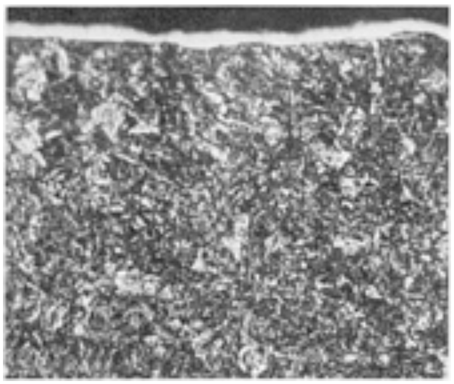

Fig. 86 4140 steel, oil quenched from 845 °C (1550 °F), tempered 2 h at 620 °C (1150 °F), surface activated in manganese phosphate, and gas nitrided 24 h at 525 °C (975 °F). Structure is white layer of Fe_2N, Fe_3N, and Fe_4N, and tempered martensite. 2% nital. 400×

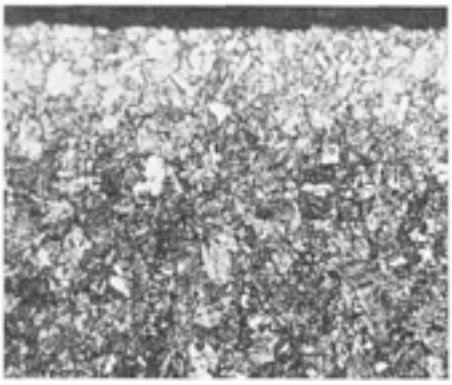

Fig. 87 Same steel and prenitriding conditions as described in Fig. 86, except double-stage gas nitrided: 5 h at 525 °C (975 °F), then 20 h at 565 °C (1050 °F). Structure consists of diffused nitride layer and a matrix of tempered martensite. 2% nital. 400×

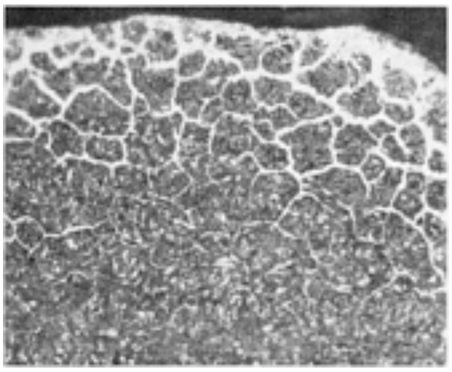

Fig. 88 H13 steel, heated to 1030 °C (1890 °F) in a vacuum, quenched in nitrogen gas, triple tempered at 510 °C (950 °F), surface activated in manganese phosphate, and gas nitrided 24 h at 525 °C (975 °F). White surface layer is iron nitride. Grain-boundary networks of nitride are present throughout the martensitic case. 2% nital. 300×

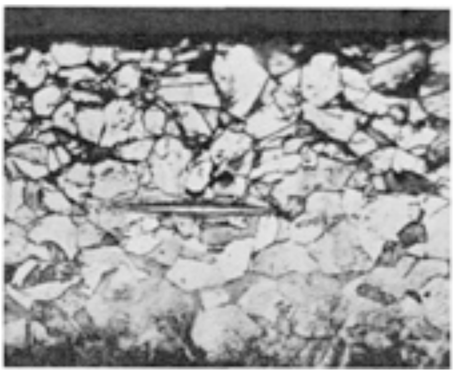

Fig. 89 18% Ni maraging steel (300 CVM),solution treated 1 h at 815 °C (1500 °F), surface activated, and gas nitrided 24 h at 440 °C (825 °F). Etching has made the nitride surface layer and grain-boundary nitrides appear black. Modified Fry's reagent. 1000×

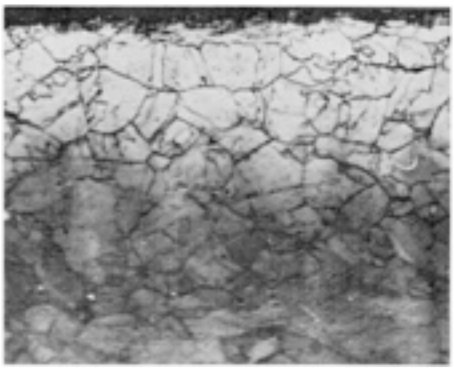

Fig. 90 Same steel and processing as Fig. 89, but etched with nital. Note that this etchant does not clearly reveal the nitrided microstructure. 1000×

Fig. 91 Same steel and processing as Fig. 89, but etched with $FeCl_3$. Iron nitride appears as black layer, similar to the specimen in Fig. 89. 500×

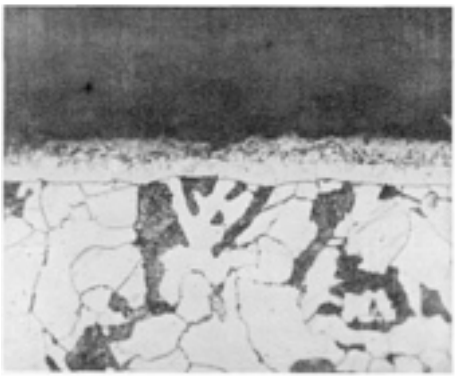

Fig. 92 4118 steel, hot rolled and annealed, surface activated, then gas nitrided 24 h at 525 °C (975 °F). White layer of iron nitride over a core of ferrite and pearlite. 2% nital. 600×

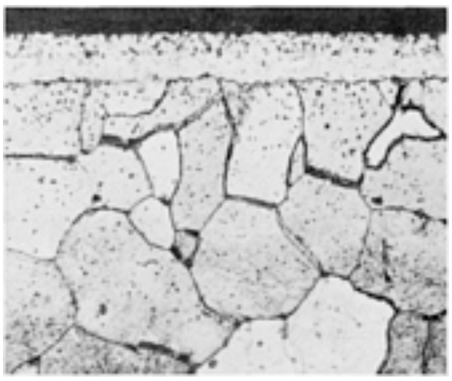

Fig. 93 1010 steel, liquid nitrided 1 h at 570 °C (1060 °F) in an aerated salt both. Layer of nitride over a core of blocky ferrite and grain-boundary carbide. No transition zone is evident. 2% nital.

700×

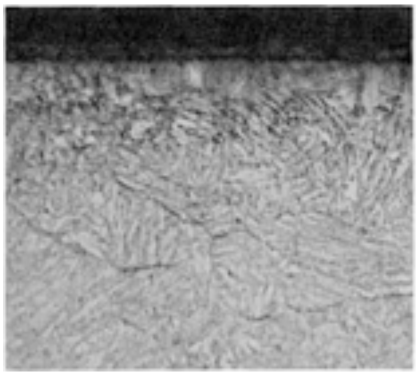

Fig. 94 Fe-0.31C-2.50Cr-0.2Mo-0.15V steel, ion nitrided 36 h at 525 °C (975 °F). Tempered before nitriding to 35 HRC. Specimen was nitrided to produce a pure diffusion zone with no white layer. The matrix is tempered martensite. 2% nital. 750×

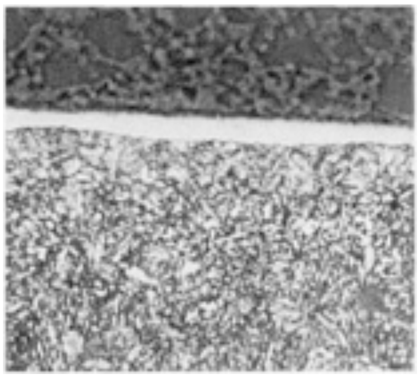

Fig. 95 4140 steel, quenched and tempered to 30 HRC, then ion nitrided 24 h at 510 °C (950 °F). Monophase surface layer of Fe_4N, plus a diffusion zone of nitride containing tempered martensite. Nital. 750×

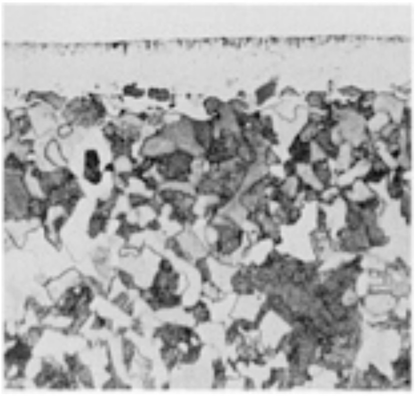

Fig. 96 SAE 1035 modified (0.20% Al added) steel, salt both nitrided 90 min at 580 °C (1075 °F) and water quenched. Surface layer of iron nitride over a matrix of ferrite and pearlite. 1% nital. 500×

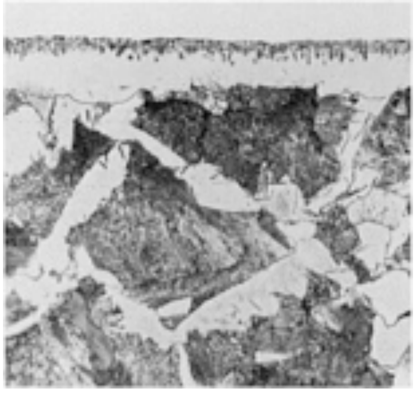

Fig. 97 SAE 1045 modified (niobium added) steel, salt bath nitrided 90 min at 580 °C (1075 °F) and water quenched. White nitride layer over a pearlitic matrix. 1% nital. 500×

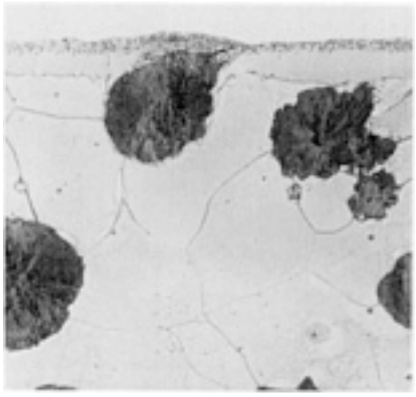

Fig. 98 Nodular ferritic cast iron, salt bath nitrided 2 h at 580 °C (1075 °F) and water quenched. Structure is a white layer of iron nitride over a core of graphite nodules in ferrite. 1% nital. 500×

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