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The microstructure of drill steel

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THESIS

FOR THE DEGREE OF B.S. IN MINE ENGINEERING.

UNIVERSITY OF MISSOURI SCHOOL OF MINES AND METALLURGY

THE MICROSTRUCTURE OF DRILL STEEL

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THE MICROSTRUCTURE OF DRILL STEELS.

The object of this thesis was to determine the microstructure of the various grades of steel used in rock drilling and to obtain if possible some general relation between the structure, composition, and hardening temperature. About 35 of the best known grades of tool steel having a carbon content of about one per cent or containing an equivalent hardening agent.

From each bar two pieces one-fourth of an inch long and one and one-half inches long were sawed. The one and one-half inch piece was then hardened and tempered as described. Most of the pieces were hardened by plunging into water at a bright cherry heat and were then tempered by allowing the color to run to a light straw. The air hardened steels were cooled in air from a white blistering heat or from a lemon yellow as described. The pieces were polished first on emery paper then on broad cloth with infusorial earth and finially with rouge. After polishing they were etched with strong nitric acid.

The microscopic examination was done under a magnification of from 500 to 900 diameters, using an oil immersion. A Bausch & Lomb microscope with arc light illumination was used. The more characteristic specimens were photographed.

No.1.

Atha Steel Company, Champion Cast steel.

ANNEALED: Masses of cementite surrounded by pearlyte Cementite is very distinct and in small islands. The pearlyte has a characteristic structure.

HARDENED: Bright cherry and drawn to a light brown temper. Cracks slightly. Field is mostly martensite and pearlyte. The structure is become very irregular. The pearlyte has segregated in dense masses and the martensite in masses, strings etc. around the pearlyte. Structure varys within the mass to a great extent. Some sorbite is present and show the martensitic structure

No. 2.

Atha Steel Co., Champion extra steel.

ANNEALED: Shows irregular areas of cementite surrounded by pearlyte. The cementite areas are about twice the pearlyte.

HARDENED: Bright cherry and drawn to a light purple. Nine hundred diameters. The structure has become coarse and blocky. The martensite occurs in fairly large areas and grades in the sorbite. Martensite about half of the field.

No.4.

Samuel Osburn. R.Mushetes extra best titanic cast steel

ANNEALED: Five hundred and thirty diameters. Shows an extremely fine grain. Most of the ground mass is pearlyte with small areas of ferrite. The pearlyte is very even and has a well developed structure.

HARDENED: Bright cherry and drawn to a very light straw. Martensitic structure ground mass of pearlyte with webb like areas of white martensite .

No.5.

Atha Steel Co. Atha air hardening.

ANNEALED: Five hundred and thirty diameters. Large regular masses of ferrite surrounded by areas of pearlyte.

HARDENED: Nine hundred diameters. Bright cherry and drawn to a very light straw. This steel has the appearance of a low carbon steel. About two-thirds of the area is white. The white material does not have a martensitic structure. The entire area is granular.

No.6.

Samuel Osburn, Mushet high speed steel.
ANNEALED: Nine hundred diameters. Feild nearly all pearlyte with a few areas of ferrite. Ferrite is in very small grains.
HARDENED: White hot and cooled in an air blast. Blistered. A peculiar net work appearance as though burned. The webb like lines are black. The remainder of the field appears about half and half granular pearlyte and ferrite. No martensitic structure.

No.9.

McInnes Crucible Tool Steel.
ANNEALED: Five hundred and thirty diameters. The ground mass is pearlyte with occasional small areas of ferrite. Regular structure.
HARDENED: Bright cherry and drawn to a dark straw. Badly cracked. Feild is mostly white martensite with some dense areas of sorbite. Has a characteristic angular appearance of over heated steel.

No.10.

McInnes Steel Company. Crucible steel.
ANNEALED: Five hundred and thirty diameters. The field is nearly all pearlyte with some very small areas of ferrite.
HARDENED: Bright cherry and drawn to a medium straw. Nine hundred diameters. About one-fifth of the field consists of large areas of martensite, The remainder is pearlyte which shows the martensitic structure.

No.11.

William Jessop & Son, Warranted cast steel.
ANNEALED: Nine hundred diameters. Shows a very fine structure. About two-thirds pearlyte. With small areas of cementite in relief.
HARDENED: Bright cherry and drawn to a light straw. Nine hundred diameters. The field is nearly all very fine martensite with about one-tenth white cementite. Shows a very crystallinestructure.

No.12.

William Jessop & Son, Warranted cast steel.
ANNEALED: Five hundred and thirty diameters. Ground mass of pearlyte with a small amount of ferrite.
HARDENED: Bright cherry and drawn to a medium straw. Shows a very uneven crystalline appearance. About half and half martensite and sorbite. The sorbite has a martensitic struccture

No. 13

Patriarch & Bell Cast Steel.
ANNEALED: Nine hundred diameters. The field is mostly pearlyte with some irregular white masses of ferrite. The structure is crystalline but not homogenous.
HARDENED: Bright cherry and drawn to a light straw. Nine hundred diameter. The field is about half and half large white areas of ferrite and darker areas of martensite. The structure is coarsely crystalline.

No. 14

Hawkridge Bros., Hawk brand.
ANNEALED: Five hundred and thirty diameters. Small irregular areas of ferrite on a ground mass of pearlyte.
HARDENED: Bright cherry and drawn to a very light straw. Nine hundred diameter. Groung mass of martensite with about one-third elongated white areas of cementite.

No. 16

Firths Best tool steel
ANNEALED: Small areas of ferrite on a ground of pearlyte.
HARDENED: Bright cherry drawn to a very light straw. Nine hundred diameters. The field is very irregular.. It seems to be all martensite of varying degrees of hardness as some of the areas are much in relief. The darker areas grade into sorbite.

No. 17

Hawkridge Bros., Sabin high speed tool steel.
ANNEALED: The field is nearly all pearlyte with a few small areas of ferrite unevenly distributed.
HARDENED: White blistering heat and cooled in air blast. Etched with great difficulty. Nine hundred diameter. Very peculiar webbed and pitted appearance. Plate like white areas with dark lines.

No. 19

Midvale Steel Company, tool steel.
ANNEALED: Nine hundred diameters. Ground mass pearlyte with a few very small areas of ferrite.
HARDENED: Bright cherry and drawn to a light straw. Nine hundred diameters. The specimen is very badly cracked. Shows a martensitic structure. White areas in relief and grading into dark sorbite. Light areas have dark round pits in them.

No.20.

Hawkridge Bros., Crucible steel.
ANNEALED: Nine hundred diameters. Small regular areas of ferrite on a field of pearlyte.
HARDENED: Bright cherry and drawn to a medium straw. Etched with difficulty. Nine hundred diameters. The field is entirely martensite. There are a few round small pitts of pearlyte and some small elevations of cementite.

No.21.

Firth & Sons, Steel Company. Stirling tool steel. Warranted.
ANNEALED: Irregular areas of ferrite surrounded by pearlyte.
HARDENED: Bright cherry and drawn to a dark straw. Nine hundred diameter. This shows a dark and a light variety of martensite.

No.22.

Firth Sterling Steel Co., Blue chip high speed steel.
ANNEALED: Small even areas of ferrite on a grouhdof pearlyte.
HARDENED: Dull cherry and drawn to a medium straw. Badly cracked. The field is apparently dark granular pearlyte some dead white areas in relief and intermediate gray areas. White areas are of about one-fourth of the field.

No.23.

Heller Bros. Co., Clay crucible tool steel. American special.
ANNEALED: Saml1 irregular areas of cementite on a field of pearlyte.
HARDENED: Bright cherry and drawn to a light straw. Nine hundred diameters. White raised areas with dark lines giving a martensitic structure and about one-half dark sorbite. The structure is very even.

No.24.

Heller Bros, Co., Clay crucible tool steel.
ANNEALED: Ground mass of pearlyte with a few small irregular lines of cementite.
HARDENED: Bright cherry and drawn to a light straw. Slightly cracked. Nine hundred diameters. The field is all a very dark granular pearlyte. A few small white areas in relief very even grain.

No.25.

Colonial Steel Co., Colonial #7 tool steel.
ANNEALED: Nearly all pearlyte with a little cementite. The pearlyte is very coarse.
HARDENED: Bright cherry and drawn to a light straw. Nine hundred diameters. The field is sorbite having a martensitic structure. Some white areas without a martensitic structure.

No.26.

Colonial Steel Co., Red star drill steel.
ANNEALED: Ground mass nearly all pearlyte. A few small unevenly distributed masses of cementite.
HARDENED: Bright cherry and drawn to a light straw. Nine hundred diameter. Very close grained. Feild about half and half martensite and sorbite with a martensitic structure.

No.27.

Swedish Steel.
ANNEALED: Very even structure. Nearly all pearlyte with small irregular areas of cementite.
HARDENED: Bright cherry and drawn to a dark straw. Nine hundred diameters. Nearly all very fine martensite with a few dark areas of pearlyte.

No.28.

Braeburm Steel Co., Crucible cast steel. Medium.
ANNEALED: Feild nearly all pearlyte having a very irregular structure. A few small irregular masses of cementite.
HARDENED: Bright cherry and drawn to a light straw. Slightly cracked. Field is all a very even martensite, very crystalline.

No.30.

Colonial Steel Co., Colonial special tool steel. "D"
ANNEALED: Very irregular lines and masses of cementite on a field of pearlyte.
HARDENED: Bright cherry and drawn to a light brown. Nine hundred diameters. The field is quite dark resembling granular pearlyte but it has a fine martensitic structure, also a few areas of cementite.

No.31.

Herman Boker & Co., Deo steel.
ANNEALED: Small irregular areas of ferrite on a field of pearlyte. Very uneven structure.
HARDENED: Bright cherry and drawn to a dark brown. Badly cracked. The field is all a dark very crystalline martensite. Very even homogenous structure.

No.32.

Herman Boker & Co., Ico steel.
ANNEALED: Smalll and evenly distributed areas of cememtite on a field of pearlyte.
HARDENED: Bright cherry and drawn to a light straw. Cracked. The field consists of martensite and sorbite having a martensitic structure. Structure is very even.

No.33.

Jones & Culver, Novo steel.
ANNEALED: Entirely very fine pearlyte.
HARDENED: Bright cherry and drawn to a light straw. Nine hundred diameters. The field is all granular pearlyte with hard white granulas of cementite. No martensitic structure

No.34.

Bethlehem Steel Co., Bethlehem drill steel.
ANNEALED; Ground mass of irregular pearlyte with a few areas of cementite.
HARDENED: Bright cherry and drawn to a dark brown. Nine hundred diameters. Field entirely martensite. The structure is a very crystalline resembling frosted zinc.

No.36.

Bethlehem Steel Co., Crucible steel.
ANNEALED: Indistinct masses of ferrite on a ground of pearlyte.
Hardened: Bright cherry and drawn to a light purple. Cracked. Nine hundred diameters. The structure is very uneven showing considerable segregation. The field consists of dark pearlyte, a lighter pearlyte having a martensitic structure and white cementite.

No. 37.

Seebohm & Dieckstahl. Best warranted cast steel, not weldable.
ANNEALED: The field is about two-thirds pearlyte and one-third cementite, very even structure.
HARDENED: Bright cherry and drawn to a light straw. Nine hundred diameter. Very peculiar granular appearance. White areas of martensite, gray areas showing a martensitic structure and dark areas of pearlyte.

No. 38.

Seebohm & Dieckstahl Ideal special self hardening
ANNEALED: About two-thirds pearlyte and one-third irregular large areas pf ferrite. Has an even but coarse structure.
HARDENED: Lemon yellow and cool slowely in air. Nine hundred diameters. Feild entirely pearlyte with a few areas of ferrite. No martensitic structure.

No. 39.

Seebohm & Dieckstahl. Punch temper.
ANNEALED: Feild about two-thirds pearlyte and one-third small granules of cementite. Even strucfure.
HARDENED: Bright cherry and drawn to a light straw. Nine hundred diameters. Feild nearly all pearlyte having a martensitic structure. The light cementite is in lagge irregular masses and are pitted. Even structure.

No.40.

Seebohm & Dieckstahl. Chisel temper. One per cent carbon.

ANNEALED: Field is nearly all pearlyte with some small irregular areas of cementite. Fine even structure.

HARDENED: Bright cherry and drawn to a light purple. Nine hundred diameter. Field appears all pearlyte with only a suggestion of martensitic structure. There are a few dark pitted areas. Very even structure.

No.41.

Seebohm & Dieckstahl. Best warranted cast steel. Seven-eighths per cent carbon.

ANNEALED: Field nearly all pearlyte with some very irregular white areas of white cementite. Very fine rather crystalline structure.

HARDENED: Bright cherry and drawn to a light straw. Nine hundred diameter. Nearly all pearlyte with some raised white areas. Only a suggestion of martensitic structure.

No.42.

Capital High speed steel.

ANNEALED: Field nearly all pearlyte with a few granular dots of cementite. Fine even structure.

HARDENED: Good cherry and drawn to light straw. Nine hundred diameter. Field nearly all pearlyte. with a few granular dots of cementite. Fine even structure.

No.43.

Dilworth Gilbert & Towne, best cast steel.

ANNEALED: Field about three-fourths pearlyte with one-fourth ferrite in large irregular masses. Coarse structure

HARDENED: Bright cherry and drawn to medium straw. Nine hundred diameter. Martensitic structure of white and gray areas with some darker pearlyte. Very even structure.

No.44.

Dilworth, Gilbert & Towne, Square deal tool steel.

ANNEALED: Field nearly all pearlyte with some cementite. Structure very uneven showing segregation.

HARDENED: Bright cherry and drawn to very light straw. Nine hundred diameter. Field nearly all dark pearlyte with white crystalline areas showing a martensitic structure. A few very white areas of cementite. Even structure.

No.45.

Dilworth, Gilbert & Towne. Square deal tool steel. special quality.

ANNEALED: Field nearly all pearlyte having a peculiar branch like structure. Very even grain.

HARDENED: Bright cherry and drawn to very light straw. Nine hundred diameter. Field is all dark martensite. Very fine and even structure.

No.46.

Charles Burgess, Special #4 high speed tool steel.
ANNEALED: Field all of very fine pearlyte. A few scattered areas of ferrite. Extremely fine grained.
HARDENED: White hot and cooled in air blast. Nine hundred diameters. Field all very fine pearlyte. A few hard granular areas. No martensitic structure. Very fine grade.

No.47.

Charles Burgess. Special #5 high speed tool steel.
ANNEALED: Small blocky masses of ferrite in pearlyte. Even structure.
HARDENED: White hot and cooled in air blast. Nine hundred diameter. Field mostly pearlyte with some granular white areas. Structures very even.

No.48.

Charles Burgess. Cyclops extra refined crucible tool steel.
ANNEALED: Entirely pearlyte. Very even and homogenous
HARDENED: Bright cherry and drawn to medium straw. Nine hundred diameter. Dark ground with white crystalline needles giving the coarse martensitic structure.

No.49.

Charles Burgess. Cyclops double x refined crucible tool steel.
ANNEALED: Field nearly all pearlyte with about one-fourth large white areas of cementite.
HARDENED: Bright cherry and drawn to a light brown. Cracked. Nine hundred diameter. Dark ground with white crystalline needles giving a martensitic structure. Structure is fairly even. The dark ground resembles sorbite.

No.50.

Charles Burgess. Cyclops triple x refined crucible tool steel.
ANNEALED: Ground nearly all very fine pearlyte with a little cementite.
HARDENED: Bright cherry and drawn to a light brown. Cracked. Nine hundred diameter. Dark ground with white crystalline needles giving a faint martensitic appearance. Ground is almost all dark paarlyte.

No.51.

Park Steel Co., Double special tool steel.
ANNEALED: Field of coarse paarlyte with about one-fifth cementite. Coarse structure.
HARDENED: Low cherry and drawn to a light straw. Ground almost all pearlyte with some irregular areas of cementite There is no martensitic structure.

No.52.

Park Steel Co., Extra quarry steel.
ANNEALED: Peculiar appearance of granular ferrite arranged in rows.on a field of pearlyte.
HARDENED: Low charry and drawn to a light straw. Nine hundred diameters. Light martensite and light pearlyte arranged unevenly. Martensite is very crystalline.

No.53.

Park Steel Co., Black diamond tool steel.
ANNEALED: Field about three-fourths pearlyte and one-fourth granules of cementite. Structure is fine and even.
HARDENED: Low cherry and drawn to medium straw. Nine hundred diameter. Ground is nearly all pearlyte with some white areas giving a martensitic structure. Structure is quite dense but uniform.

No.54.

Crucible Steel Co. of America. Rex high speed steel.
ANNEALED: Field nearly all fine pearlyte with some granules of cementite. Pearlyte seems to be of two different degrees of hardness. Fairly fine grain.
HARDENED: Good cherry and drawn to a dark straw. Nihe hundred diameter. Pearlyte with small white granules of cementite. Very even structure. No martensite.

No.55.

Sanderson Bros. & Co., Special cast steel.
ANNEALED: Small well defined areas of ferrite surrounded by pearlyte. Structure is very even.
HARDENED: Bright cherry and drawn to a light straw. Nine hundred diameters. Very fine pearlyte and white hard areas. Slight martensitic structure in places. Characteristic salt and pepper appearance.

No.56.

Sanderson Bros. & Co. Self hardening steel.
ANNEALED: Field about one-third pearlyte and about two-thirds ferrite. Very coarse structure.
HARDENED: ...Heated to lemon yellow and cooled in air. Nine hundred diameters. Field of pearlyte with small granular areas of cementite and some dark pitts. No martensitic structure. Very fine grain.

No.57.

Sanderson Bros. & Co. Double special cast steel.
ANNEALED: Mostly pearlyte apparently of two kinds. One slightly darker than the other. Each occupies about one-half of the field.
HARDENED: Good cherry and drawn to a light straw. Nine hundred diameters. Ground almost all pearlyte with a few specks of cementite. No martensitic structure. Fine grain.

No.58.

Cresent Steel Co. Self hardening.
ANNEALED: Nearly all pearlyte with about one-fourth large granular masses of ferrite.
HARDENED: Lemon yellow and cooled slow in air. Nine hundred diameters. Very fine pearlyte. No martensitic structure.

No.59.

Cresent Steel Co. Double special steel.
ANNEALED: Field nearly all of very fine pearlyte with a few small areas of cementite. Structures very fine andeven even. HARDENED: Good cherry and drawn to a dark straw. Nine hundred diameters. Very fine structure. Mostly pearlyte with fine white specks. No martensitic strucutre.

No.60.

Cresent Steel Co. Cresent extra "E"
ANNEALED: Small masses of ferrite on a field of pearlyte. Very even structure.
HARDENED: Low cherry and drawn to a light straw. Nine hundred diameters. Dark pearlyte with white crystalline needles giving a martensitic structure. Very crystalline but fairly even grain.

No.61.

Halcomb Steel Co. Standard tool steel.
ANNEALED: Field all pearlyte having a peculiar crystalline appearance. There are a few small areas of cementite.
HARDENED: Good cherry and drawn to a light straw. Nine hundred diameters. Very good martensitic structure formed by black needles on a white field. Structure is very even.and very crystalline.

No.62.

Halcomb Steel Co. Extra warranted tool steel.
ANNEALED: Fine blocky masses of ferrite upon a field of pearlyte. Fairly even structure.
HARDENED: Good cherry and drawn to a light straw. Nine hundred diameters. Mostly pearlyte with some white material giving a faint martensitic structure. The structure is very even.

No.63.

Halcomb Steel Co. Special tool steel.
ANNEALED: Small areas of ferrite on a field of pearlyte. Very even and homogenous structure.
HARDENED: Good cherry and drawn to light straw. Nine hundred diameters. Field is all extremely fine martensite. Very even.

No64.

Halcomb Steel Co. Double special tool steel.
ANNEALED: Fine pearlyte with about one-third of the field cementite. Structure is fine and even.
HARDENED: Good cherry and drawn to very light straw. Field is entirely pearlyte. No martensitic structure. Structure is very fine.

No.65.

Halcomb Steel Co. Double extra tool steel.
ANNEALED: Small irregular grains of ferrite on a field of pearlyte. Fairly even structure.
HARDENED: Good cherry and drawn to a light straw. Nine hundred diameters. White and dark needle giving a fine martensitic structure.

No. 66.

Halcomb Steel Co. Caben high speed tool steel.
ANNEALED: Field all extremely fine pearlyte with a few very small areas of ferrite.
HARDENED: White blistering heat and cooled in air blast. Nine hundred diameter. Fine pearlyte which is in blocky areas surrounded by fine black lines, characteristic burned appearance.

No.67.

Vulcam Steel Co. Superior.
ANNEALED: Field nearly all a fine grain of pearlyte with a few large irregular masses of cementite.
HARDENED: Good cherry and drawn to a light straw. Nine hundred diameters. Very even martensitic structure with some sorbite.

No.68.

Vulcam Steel Co. Vulcam extra drill steel warranted.
ANNEALED: Field nearly all pearlyte with small areas of cementite. Structure homogenous.
HARDENED: Good cherry and drawn to a dark straw. Nine hundred diameters. All pearlyte with a few white specks. No martensitic structures. Structure is very even.

No.69.

Vulcam Steel Co. Vulcam high speed steel.
ANNEALED: About one-half very fine pearlyte with irregular and granular masses of ferrite.
HARDENED: White blistering heat and cooled in air blast. Nine hundred diametors. Peculiar granular appearance. The field is very fine pearlyte with small white granules of ferrite. No martensitic structure.

Conclusions.

The conclusions from this thesis are only of the most general character. However, from a large number of observations it is possible to draw certain general inferences with considerable accuracy.

Steels, containing only carbon as a hardening element appear to be best prepared for rock drilling when the microstructure shows about half and half martensite and sorbite and when the structure is fairly even. The steel having this composition is both tough and hard. When a steel of about one per cent carbon is hardened at a bright cherry and the temper is drawn to a light straw about the prpper proportion of martensite is present. The tempering seems to break up part of the martensite formed by hardening and to give the remainder a finer structure. Steels of over one per cent carbon are very apt to crack when hardened above a dull cherry and certain alloy steels cannot be hardened in water at all.

The formation of martensite is greatly hindered by the presence of other elements. Nickel forms an alloy which does not change its structure upon hardening. Other alloy and air hardening steels only change in the fineness of their structure upon hardening. Whatever change of composition or the condition of the iron may take place it is obscured by the presence of manganese, vanadium etc. Some air hardening steels show a burned structure when held at a white heat in the presence of air for several minutes.

Sorbite is formed under the conditions of hardening in many of these steels. It shows as a transition between martensite and pearlyte. It usually shows a martensitic structure.

Small amounts of manganese, nickel chromium and vanadium do not supress the formation of martensite but they make the structure more finely crystalline.

Small amounts of silicon have no appreciable effect.

Ordinary steels containing over one and two-tenths per cent of carbon usually contain other hardening elements which suppress the formation of martensite.

High manganese steels are unchanged upon hardening. No martensite is formed.

CHEMICAL ANALYSES

BY E.E.LIST

No.1.
C. 1.354% Si. 0.019% Low in S & P Mo. & Mn.

No2.
C.0.985% Si. 0.109% Mo. & Mn.

No.3.
C. 2.000% Si. 0.032% Mn.2.490%

No.4.
C. 0.6309% Si. 0.040% Mn. & Cr.

No.5.
C. 1.440% Si. 0.111% Mn. & Cr.

No.6.
C. 1.500% Si. 0.056% Mn. & Cr.

No.7.
C. 1.000% Si. 0.024% Mn.

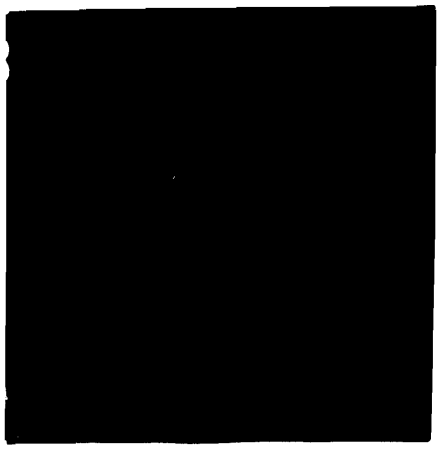
No.8.
C. 1.25% Si. 0.03% Cr. & Mn.

No.9.
C. 0.7030% Si. 0.0258% Mn.

No.10.
C. 1.042% Si. 0.0258% Mn. Cr. & Ni.

No. 11.
C. 1.590% Si. 0.033% Mn. Ni. & Va.

No.12.
C. 0.810% Si. 0.070% Mn.



#9 ANNEALED

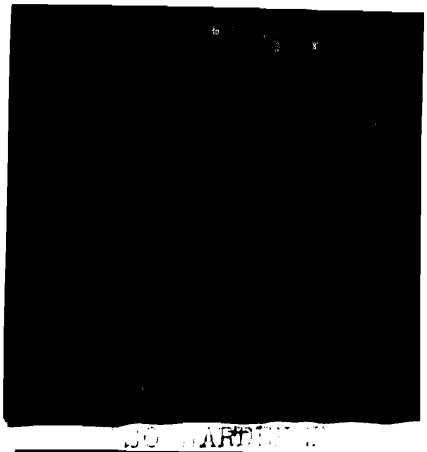
#9 HARDENED

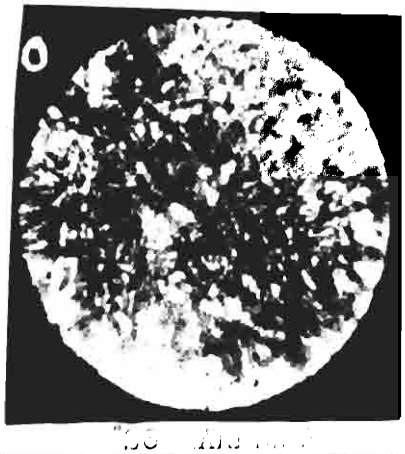
#11 HARDENED

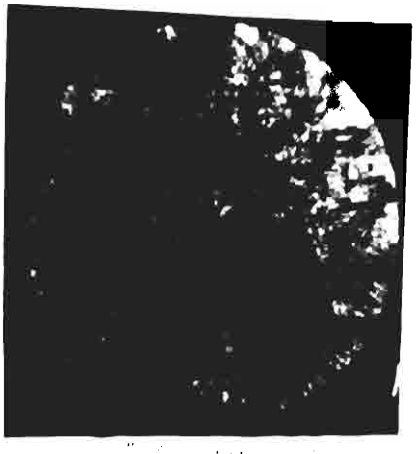
#14 HARDENED

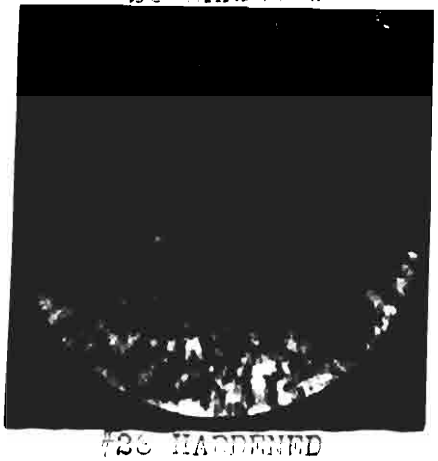
#17 HARDENED

#20 ANNEALED









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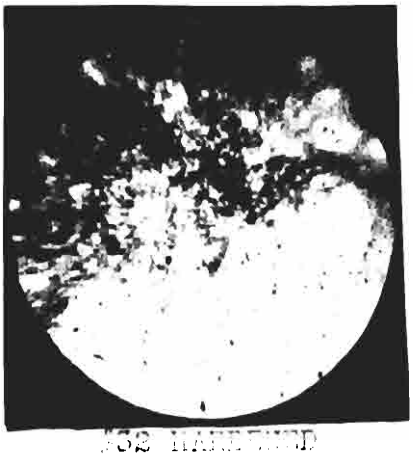

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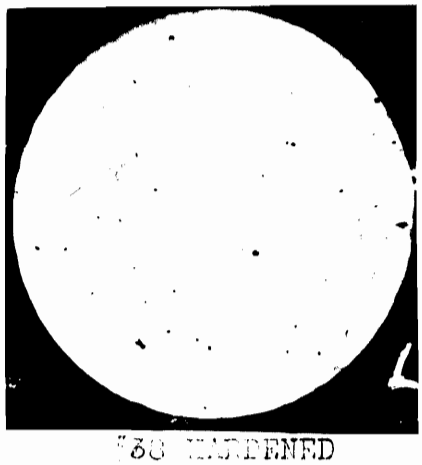
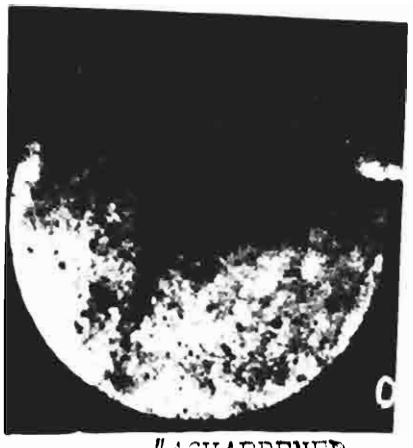


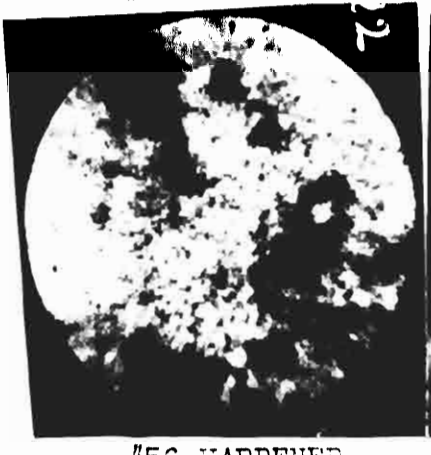
#38 HARDENED

#39 HARDENED

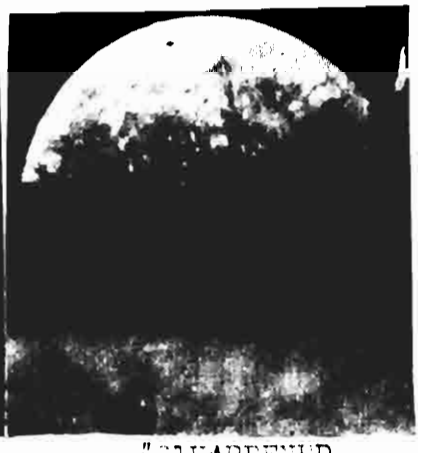


#40HARDENED

#52 HARDENED

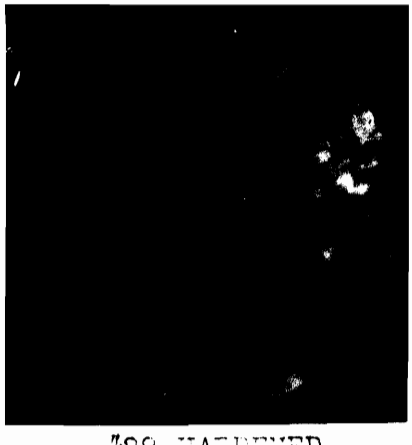


#56 HARDENED



#51HARDENED

#27HARDENED
4 seconds



#28 HARDENED