A PHYSICO - CHEMICAL STUDY OF HOT-WORK TOOL STEELS

THESIS FOR THE DEGREE OF MET. ENG.

Edwin A. Brophy

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THESIS

Steel

A Physico - Chemical Study

Of

Hot - Work Tool Steels

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Met. E.

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THESIS

A C K N O W L D G M E N T S

The writer wishes to express his sincere thanks and gratitude to Professor Henry E. Publow for his kindness and helpful suggestions, also for his part in making this theisis possible.

Also my appreciation and thanks to Mr Norman I. Stotz, Superintendent and Mr John A. Nelson, Metallurgist, Braeburn Alloy Steel Corporation for samples, tests, and numerous suggestions. Their help cannot be stressed too highly.

Hot Work Tool Steels

ABSTRACT

This thesis consists of:

1. Typical analysis as used to-day.

2. Discussion of the general factors to be considered in the application of such steels.

3. Effects induced by the major alloying elements.

4. A very comprehensive study of the physical properties at normal (room) and elevated temperatures.

5. Dilatometric change study by the Chevenard Dilatometer.

6. Photomicrographic study of the important types.

7. The heat-treatment and particular application each type is best suited for.

HOT WORK TOOL STEELS - ANALYSIS

Hot work tool steels have been developed through industrial research over a long period of time. Therefore, the analysis involved seem to be legion. This of course is a decided disadvantage to manufacturer as well as consumer. Each type developed seems to carry with it, in the natural course of time, several off-spring. The off-spring fortunately frequently means the death of the parent-analysis. The main types of analysis (13) are listed on the following page. It is to be noted that tungsten or chromium, usually both, are the main alloying elements in hot work steels. The effect of these elements is discussed separately. Nickel seems to have been somewhat neglected as an alloying element in hot work steels, but it is my opinion that future research will show the possibilities of both nickel and molybdenum for this class of work.

Each analysis presents certain advantages for particular applications, but the large tonnage consumption is held to six or seven grades of steel. Therefore, these main types have been selected, and will be described in detail. Of the other grades the important points only will be mentioned.

HOT WORK TOOL STEELS - ANALYSIS.

Type	C.	Mn.	P&S. (max)	Si.	Cr.	V.	W.	Co.	Mo.	Ni.
1	.65/73	.15/30	.025	.15/.30	3.75/4.25	.85/1.0	17.5/18.5	-	-	-
2	.50/55	.15/30	"	.15/.30	3.75/4.25	.85/1.0	17.5/18.5	-	.15/30	-
3	.50/55	.15/30	"	.15/30	3.75/4.25	.85/1.0	17.5/18.5	4.0/4.5	.75/1.0	-
4	.30/35	.15/30	"	.20/35	3.00/3.50	.30/50	10.0/12.0	-	-	-
5	90/1.05	.20/40	"	.25/40	3.50/4.50	-	-	-	-	-
6	.40/50	.20/30	"	.80/1.0	1.30/1.50	.20/30	1.5/2.0	-	-	-
7	.30/40	.20/35	"	.80/1.0	4.75/6.00	.15/25	4.75/6.0	.40/.60	.15/30	-
8	.45/50	.15/25	"	.30/50	4.25/4.75	.20/30	1.75/2.0	-	.85/1.0	-
9	.35/40	.15/30	"	.20/35	6.00/8.00	.30/.50	6.00/8.0	-	-	-
10	.40/45	.15/30	"	.15/30	3.00/3.50	.30/.50	12.0/14.0	-	-	-
11	.30/35	.30/50	"	.10/15	13.00/15.0	-	-	-	-	-
12	.40/50	.50/70	"	.20/35	2.50/3.0	-	-	-	-	-
13	.10(max)	.30/60	"	.15/30	-	-	-	-	.20/30	1.5/2.0

EFFECTS INDUCED BY ALLOYING ELEMENTS - HOT WORK STEEL

Carbon:

In plain carbon steel the effect is to lower the critical range, that is, the hardening; increase the tensile strength with a corresponding increase in brittleness. With the presence of alloys, especially tungsten, inherent brittleness is present, and usually develops as checks or cracks on the edges of the rolled or forged sections. In the iron-tungsten alloys a carbon content of .55 to .75% seems to forge with much greater ease and less loss than either low or high carbon percentages. When the carbon falls much below .55% there is no particular trouble with exterior cracking, but there is a tendency for the internal structure to become stringy or fibrous. This type of structure is usually referred to as a woody structure, and it is possible that it is due to rejection of excess tungsten (Fe_3W_2) when an insufficiency of carbon is present to form the normal tungsten carbides, - Fe_4W_2C. When higher carbon- greater than .75% - is present, there is an excess of large carbide globules, which might account for the characteristic brittleness.

It should be noted, that according to the research work of Sykes, a carbonless tungsten alloy of this type is hardenable, and yet is without allotropic modifications. The hardening in such cases is purely by particle precipitation. When carbon is present it assumes the characteristics of steel and hardens by the regular martensitic method, that is, by quenching.

Without carbon the matrix is wholly ferrite.

According to Sykes these carbonless tungsten and molybdenum alloys possess red-hardness after quenching and reheating to 1300°F, (200° above the tempering temperature of high speed steel).

The percentage of carbon in hot work steels has a decided effect on the Ar critical points. With approximately .7% carbon and 18% tungsten we have two well defined points on cooling, namely, Ar_1- 710°C and Ar_2- 410°C. (see dilatometric curve). With the same tungsten content and the carbon reduced to approximately .50% there are still two critical points on cooling; but the Ar_1 is the more intense, whereas with the higher carbon the Ar_2 showed the greater intensity. The Ar_2 change is the point of transformation to the martensitic phase, and of course is accompanied by a tremendous expansion.

EFFECTS OF ALLOYING ELEMENTS

Vanadium:

There does not seem to be any very positive or definite facts concerning the presence of vanadium in steel. It forms solid solutions with alpha iron, but less than 2% will completely eliminate the gamma form of iron.
The presence of vanadium has little or no effect on the critical points.
Vanadium, like silicon and manganese, has always been a benefit to steel in helping to cleanse and degasify it. It has also the marked tendency to control or prevent excessive grain growth while steel is at elevated temperatures during working or heat treating. For this reason it is common practice, when extreme hardness is required, (and vanadium is present) to increase the temperature for hardening. The depth of the case hardness is considerably increased by a small addition of vanadium. It is to be noted that large additions of this element are not necessary. In most, perhaps all steels, the percentage rarely exceeds 2%. This higher percentage is used only in a few special high speed steels. It is usually 1% or less.
It is thought by many that the addition of a small amount of vanadium lends strength and endurance to working edges of the tools. This is undoubtedly true, but it is probably

Vanadium (contd)

due to the limiting of the grain growth and increasing the homogeneity, rather than any particular characteristic of vanadium.

The forging and rolling of alloy steels containing vanadium is not affected to any appreciable degree by vanadium up to percentages of 2%. Many mill men are of the opinion that it helps forging, due to aiding solution of carbides at high temperatures. This is very problematical.

EFFECTS OF ALLOYING ELEMENTS

Cobalt:

This element has gained much greater use of late in hot work and high speed steels. It is capable of lending strength and resistence at elevated temperatures. It forms a solid solution with alpha and gamma iron, and therefore, renders solid solution hardness to steels containing it.

The effect on the critical points is very slight.

Of late the percentages used have greatly increased; some high speed steels containing up to 2%.

The presence of cobalt in steels presents much trouble with decarburized soft skins. For some unknown reason the presence of cobalt enhances decarburization during working operations, especially when many reheatings are necessary. Depths of decarburization up to 1/16" are not uncommon. The evidence is that cobalt is not oxidized, but tungsten is oxidized and forms a yellow powder (WO_3?) on the forging tools. None of the salts of cobalt are yellow, whereas the color of tungstic acid (WO_3) is an orange yellow. This condition never occurs in the absence of cobalt. Therefore, it might be likened to a catalytic action, - The cobalt acting as the catalytic agent.

Cobalt (contd)

The outside skin frequently runs as low as .10% carbon, and presents a problem for heat treating.

This alloy is structurally weak, and while not much difficulty is encountered in forging, yet the outside decarburized skin when subjected to rolling, particularly in squares and flats, tears away at the corners, due to its absolute lack of tensile strength. This is why is it important to grind away the decarburized skin from the billets after hardening and before rolling.

EFFECTS OF ALLOYING ELEMENTS

Molybdenum:

This element, like tungsten and chromium, offers much hardness at elevated temperatures.

Molybdenum is gradually, but surely, destined to play a large roll in hot work and high speed steels of the future.

In Syke's research he worked with iron-molygdenum and iron-tungsten alloys, and he found the behavior of molybdenum not unlike that of tungsten. Much work has been done on substituting molybdenum for tungsten in high speed and similar steels. It has been found that one part of molybdenum is equivalent to 2.5 parts tungsten. The resulting steels are not quite the equal of the tungsten steels for resistence to wear, but if need be they could be substituted.

Molybdenum is better when used as an adjunct to tungsten and chromium. The increase in red hardness is quite pronounced.

The same decarburization trouble experienced in forging cobalt steels is presented with the working of molybdenum steels, only to a greater extent. Some think the soft skin is the result of oxidation of molybdenum to MoO_3

Molybdenum (contd)

and its subsequent volatilization. I think the molybdenum acts similarly to the cobalt, that is, as a catalytic agent, and causes decarburization.

To prevent this "soft skin" forming it is necessary to forge under a neutral gas condition, or under a film of borax melted across the ingot. Neither of these methods are very practical in a steel mill. So until some method is found whereby the soft skin can be prevented, it is hardly likely that molybdenum will ever displace tungsten except, perhaps, as a war-time emergency owing to the scarcity of domestic tungsten.

EFFECTS OF ALLOYING ELEMENTS

Chromium

There is nothing very definite on the action or effect of chromium in hot work steels. It is, however, a valuable adjunct to tungsten in giving resistence to heat at elevated temperatures, especially the resistance to softening and erosive wear. It also increases the toughness somewhat.

It is quite commonly thought that the presence of chromium has a tendency toward greater carbide solution, and increases the homogeneity of the grains. Microscopic examination of varying percentages of chromium shows a great change in the nature of the austenite grains.

The critical points are not materially effected by high or low chromium percentages,- any change is simply due to sluggishness and atomic immobility induced by this element.

In the working of steels containing chromium the effect is noticed with .50%, - it has a decided stiffening effect. This is due, as with tungsten, to atomic sluggishness. Chromium acts like tungsten in many respects, and a high chromium steel without tungsten resists heat effects remarkably well. It also induces air-hardening properties. A steel with 13% chromium (high carbon) air hardens to a

(Chromium contd)

Rockwell C - 62, and resists exposure to high temperatures reasonably well. Stainless steel at one time was used extensively for hot work purposes.

With chromium, as with tungsten, the forging is carried on very slowly and cautiously to get the metal to "flow", and also is closely watched to prevent temperature from falling to the air hardening range, - about 1700°F.

When the percentage of Cr is above 2% with normal carbon the actual abrasive hardness of the chromium, together with its air hardening features, begin to present themselves. The presence of Cr necessitates a much longer soaking temperature for forging and heat treating. This is probably due to the high specific heat of the alloy, and also the induced sluggishness from the Cr.

Chromium, like tungsten, contributes deep hardening characteristics to the steel.

The sluggishness of Cr alloys enables the steels to withstand considerable heat due to its tendency, owing to atomic immobility, to inhibit the breaking down of the martensitic grains.

EFFECTS OF ALLOYING ELEMENTS

Tungsten

The solubility of tungsten in iron varies with the temperature. At low temperatures 8 to 10% seems to be the limit of solubility, while at elevated temperatures, approaching the melting point, the solubility rises to nearly 35%. The tungsten that fails to dissolve is precipitated as Fe_3W_2. When Carbon is present the tungsten forms the compound Fe_4W_2C.
The major element in present day hot work steels is tungsten, and it is also of major importance in developing red-hardness and heat resistence. It forms a solid solution with iron. It has the ability of retaining its hardness at elevated temperatures, and for this reason is common in hot work tool steels.
It has little or no effect on the critical points, although it is commonly thought to raise them. Any change in the critical points is due to sluggishness caused by the highly alloyed condition of the steel, setting up atomic immobility. Also the diffusion of carbon is very slow, and frequently sufficient time is not allowed after the Ac manifestation before cooling. This results in a low carbon martensitic phase and a critical change at an

elevated temperature. But this is not a normal condition; - the steel is not in equilibrium. Time has been denied for complete solution of the carbon. It is fairly well conceded, however, that tungsten does lower the carbon of the eutectoid point.

Owing to the atomic immobility and sluggishness of the elements caused largely by the presence of tungsten, it is necessary to use hardening temperatures much in excess of that used for regular steels (this applies to steels with a tungsten content greater than 7%) to give ample time for the solution of compounds of tungsten such as Fe_3W_2 and Fe_4W_2C. A steel containing 10% tungsten requires a temperature greater than 2100°F to insure complete solution of the tungsten compounds.

Just as the presence of tungsten raises the temperature necessary for hardening, it likewise raises the forging and rolling temperatures. This, also, is due to the atomic immobility of its compounds.

The element tungsten induces in steel the property of air-hardening and deep penetration hardness. With high tungsten steels, say above 12%, the hardness obtained from air-hardening is practically the same as that obtained from oil quenching. This characteristic property of air-hardening

Tungsten (contd)

presents difficulties in forging and rolling opporations, and if the temperature of the steel falls much below 1700°F the metal stiffens perceptibly.

Int the forging operations frequent reheatings are necessary, due to this hardening effect as the temperature drops.

At quenching temperatures high tungsten steels are entirely austenitic, which is retained on quenching. The presence of tungsten increases the tempering temperature at which austenite is transformed into the hard martensitic phase.

Tungsten also gives deep hardening properties to steel.

HOT WORK TOOL STEELS - APPLICATION

The requirements demanded and the factors involved in destroying dies should be given careful study before recommending or applying any particular type of hot - work analysis.

The application of the correct type of analysis and the proper heat-treatment are the all deciding factors in the life of hot-work dies.

The main factors to study before applying any steel are: temperature involved (maximum and minimum), length of time die is in contact with heat, temperature to which die rises, cooling or lack of cooling conditions, contact or lack of contact with water or oil, lubrication, sudden changes of temperature, physical stresses such as torsion or impact, etc. If careful thought were always given to these salient factors fewer failures would be experienced in the application of hot work tool steel. The heat treatment of course is vital, as too much stress cannot be placed on this subject. Carefulness and proper furnace control is always a requisite. The Rockwell hardness is of great importance, and it has been my experience that heat treaters and shop men are prone to consider extreme hardness necessary to the life of the die. In the vast majority of cases the exact opposite is true. Rarely in hot work application is a hardness exceeding Rockwell C-50 necessary for long life. In most cases much less than this value is desirable. The lowest hardness that will withstand erosion is best, as the extreme hardness sets up a marked susceptibility to heat-checking which soon causes the breakdown of the die.

TYPE I

Analysis:

C	-	.65-	.75
Mn	-	.15-	.30
Si	-	.15-	.30
Cr	-	3.75-	4.25
Va	-	.85-	1.00
W	-	17.50-	18.50

As shown by the analysis, this is an 18:4:1 type of high speed steel. At one time this analysis was widely used for hot work purposes. The high tungsten - chromium content offers much resistance to erosion and elevated temperatures; but with the high carbon percentage the alloy is prone to set up heat-checks when in contact with high temperatures for any length of time. The high carbon - tungsten content also induces extreme brittleness that prevents its use on work where any shock is involved. When used it is necessary to temper at a very high temperature to increase the ductility and impact values.

Of late years this analysis has found very little use for purposes other than cutting tools where red-hardness is required. From this analysis, however, most tungsten hot work steels have evolved; hence its inclusion.

TYPE I

Heat Treatment:

Forging	-	1750° - 2100° F
Annealing	-	1600 - 1650°
Brinell	-	207 - 228

Rockwell Hardness after Oil Cooling:

		2250° F - Oil	2400° F - Oil
No Draw	-	C - 66	C - 67
1000°F	-	65	65
1100°	-	65	66
1200°	-	62	63
1300°	-	61	61

Recommended Hardening Treatment:

Preheat	-	1500°F
Quench	-	2250° Oil or Air
Draw	-	1150° - 1250°
		(according to requirements)

TYPE I

Charpy Impact Values in Foot Pounds

Heat Treatment				
Quench	Temp. °F	Draw °F	Charpy Values	Rockwell Hardness
Oil	2250	1100	3.14	C 61
"	"	1150	3.37	59
"	2380	1050	2.02	64
"	2000	1200	2.90	49
"	2150	"	"	57
"	2250	-	"	59
"	"	1100	2.62	58
"	"	1200	"	55
Air	"	"	2.50	54
Oil	2300	"	2.62	61

TYPE I

Tensile Properties - At Room Temperature

Analysis:

C - .70%

Tensile Strength lb/SqIn.	Yield Strength lb/SqIn	Elongation %	Red. of Area %	Hardness Rock.	Hardness Shore	Heat Treatment
322750	YS*TS	1.57	0	C 59	81	2300oF Oil 1100 Draw
330860	275000	0.63	.56	55	73	2300°F Oil 1200 Draw

At Elevated Temperatures

900° and 1100°F respectively

175600	-	2.0	1.2	C 42	-	2100°F Air 1250 Draw
145020	-	6.0	14.8	-	-	2100°F Air 1250 Draw

TYPE I

Tensile Properties - At Room Temperature

Analysis:

C - .70%

Tensile Strength lb/SqIn.	Yield Strength lb/SqIn	Elongation %	Red. of Area %	Hardness Rock.	Hardness Shore	Heat Treatment
322750	YS=TS	1.57	0	C 59	81	2300oF Oil 1100 Draw
330860	275000	0.63	.56	55	73	2300oF Oil 1200 Draw
At Elevated Temperatures						
900° and 1100°F respectively						
175600	-	2.0	1.2	C 42	-	2100°F Air 1250 Draw
145020	-	6.0	14.8	-	-	2100°F Air 1250 Draw

TYPE I

Typical Uses - Hot Work

Automobile Valve Seats

Plungers for Upsetting Machines

Shear Blades

Heading Dies

TYPE I

Typical Uses - Hot Work

Automobile Valve Seats

Plungers for Upsetting Machines

Shear Blades

Heading Dies

DILATOMETRIC OBSERVATION

Type 1

Analysis:

C	-	.69
Mn	-	.23
Cr	-	4.01
Va	-	.98
W	-	17.96

Nearly any type of curve can be obtained from this type of steel. The normal heating and cooling curve is as shown in this chart. Time and temperature are factors in the position of the critical points.

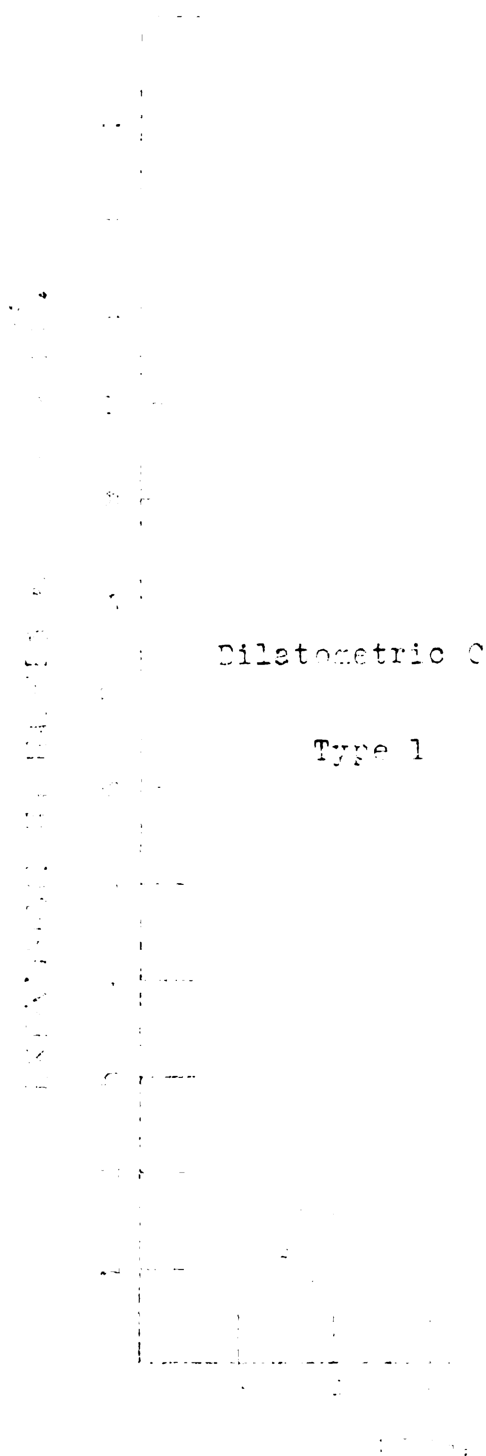
The test specimen was heated to 970°C and showed a critical transformation (Ac) at 800° - 850°C. The specimen was carried to a temperature of 970°C, before starting cooling, to insure the complete solution of the carbides. Two definite cooling transformations are shown; Ar_1 - 725°-700°C and Ar_2 - 420°-310°C. The intensity of the Ar_1 point is very slight, but the Ar_2 point shows a very large expansion over a wide range of temperature. This latter point of course is the martensitic hardening range of high speed steel. The expansion being due to the formation of martensite,

TYPE 1

Dilatometric Observation (contd.)

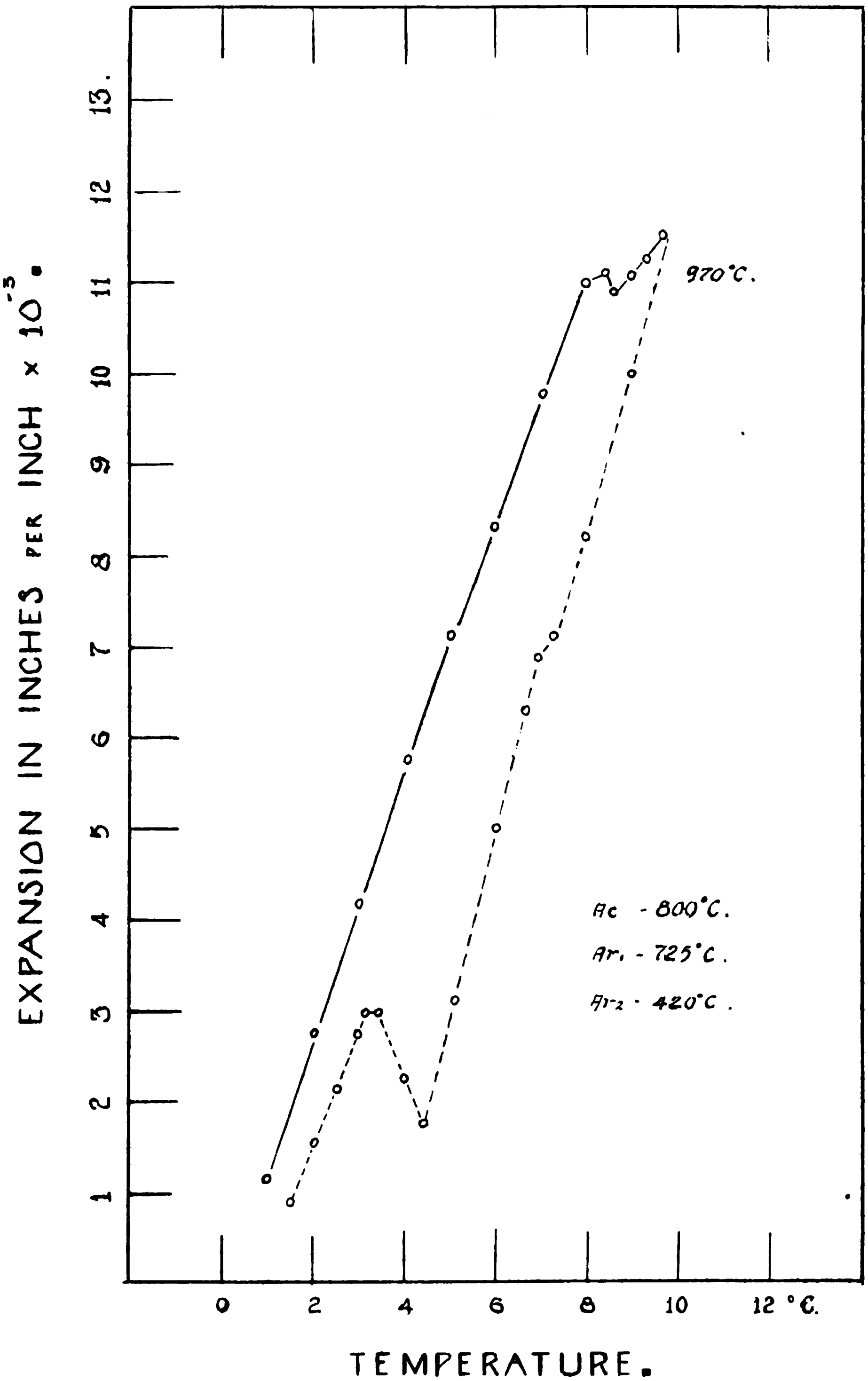
This specimen shows some contraction at the point where cooling was discontinued, due probably to retained austenite. Tempering would eliminate this condition.

It should be mentioned that if cooling of specimen commences after the Ac transformation, before sufficient time has been given for the complete solution of carbides, the martensite will be of low carbon content and will result in raising the Ar point, and cause a greater intensity of the Ar_1 point. This, however, is not a normal condition. This steel is not in equilibrium.



Dilatometric Curve

Type 1


EXPANSION IN INCHES PER INCH × 10⁻³.
1
2
3
4
5
6
7
8
9
10
11
12
13.
0
2
4
6
8
10
12 °C.
TEMPERATURE.
970°C.
Ac - 800°C.
Ar1 - 725°C.
Ar2 - 420°C.

TYPE I

Two photomicrographs are shown at high magnification, (x2400).

Photomicrograph 1 shows this steel in the annealed condition, and is a very good example of the large excess grains of tungsten compounds.

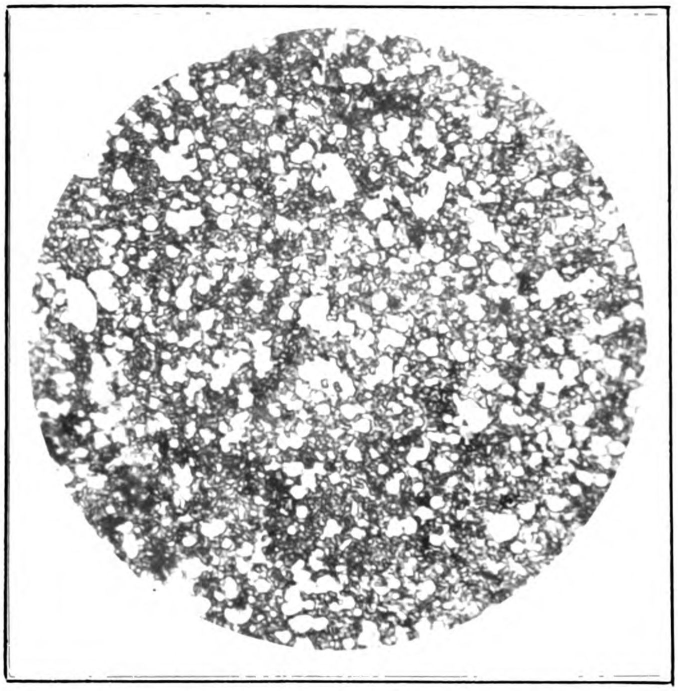
Photomicrograph 2 depicts the steel in the hardened untempered condition. The large austenitic grains are very pronounced. The matrix shows a slightly martensitic condition with globules of tungsten carbide interspersed throughout the matrix. These are the excess compounds of tungsten that failed to go into solution.

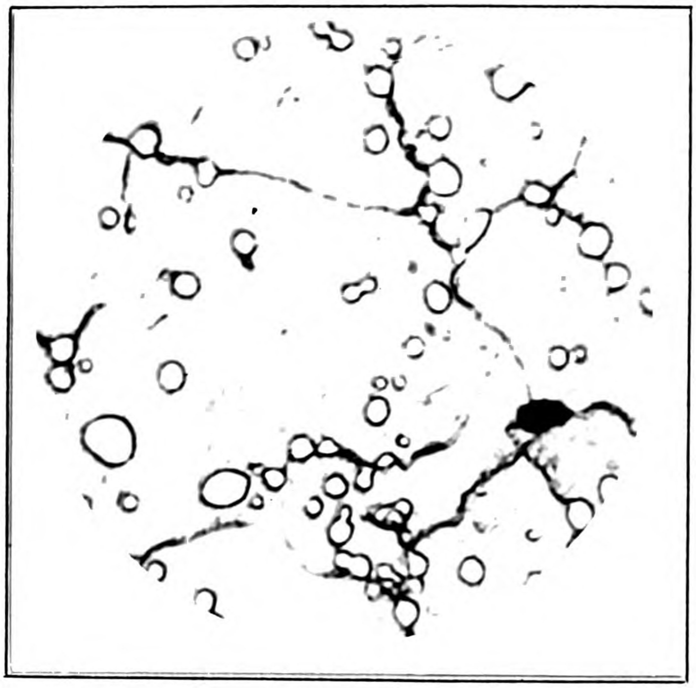
Fig. 1

X 2400

Fig. 2

X 2400





TYPE 2

Analysis:

C	-	.50	- .55
Mn	-	.15	- .30
Si	-	.15	- .30
Cr	-	3.75	-4.25
Va	-	.85	-1.00
W	-	17.50	- 18.50
Mo	-	.15	- .30

In recent years this analysis has gradually found a much wider application for hot work purposes. With the exception of the reduction of carbon to .50% and a small addition of molybdenum, this steel is the same chemically as Type 1.

The lowering of the carbon removes most of the brittleness; see comparative tensile tests, inherent to high tungsten - high carbon steels. By lowering the carbon the tensile strength is not greatly reduced, yet the elongation is increased four fold, while the reduction of area is trebled. The lower carbon content of course gives considerably lower hardness figures after quenching, but this is helpful in preventing heat-checking.

TYPE 2

For certain applications Rockwell hardnesses as low as C 35 are frequently necessary. With high carbon steel, fine hair-line heat checks set up quickly from contact with high temperatures, - this is not the case when the carbon percentage is lower with corresponding lower Rockwell hardness figures. This type of steel does not always contain a percentage of molybdenum, but the addition of a small amount (.50%) is a decided improvement in the life of the steel. I have seen gripper dies working against Silcrome valves produce 35,000 valves without the molybdenum addition, and better than 200,000 valves with the addition of .35% molybdenum.

TYPE 2

Heat Treatment:

Forging - 1850°-2000°F

Annealing - 1550o-1600°

Brinell - 217 - 235

Rockwell Hardness after Oil and Air Cooling:

	2000°F	2100°F	2250°F
No Draw -	C 49	C 55	C 59
1000°F -	51	55	59
1100 -	48	53	58
1150 -	48	52	56
1200 -	47	50	54
1250 -	38	40	45
1300 -	37	38	43

Recommended Hardening Treatment:

Preheat - 1500°F

Quench - 2000°-2150°F (oil or air)

Draw - According to hardness desired.
A long draw is very important.

TYPE 2

Analysis:

C	-	.50
Cr	-	4.05
Va	-	0.97
W	-	18.36

Charpy Impact Values in Foot Pounds

Heat Treatment Quench	Temp. °F	Draw	Charpy Values	Rockwell Hardness
Oil	2000	1200	2.9	C 47
"	2150	"	"	51
"	2250	-	"	59
"	2250	1100	2.6	58
"	2250	1200	2.5	54
"	2300	1300	2.6	55

Tensile Properties - At Room Temperatures

Tensile Strength lb/SqIn.	Yield Strength lb/SqIn.	Elongation %	Red. of Area %	Hardness Rock.	Hardness Shore	Heat Treatment
245,130	185,000	3.12	1.12	C 50	62	2250°F Oil 1200 Draw

TYPE 2

Typical Uses - Hot Work

Nut Dies, Large Size - Harden in Forge Fire, Face only.

1950°- 2000°F Air Cool

Nut Dies, Small Size -

2250°F Air
1200 Draw

Gripper Die Valves -

2050°F(packed) Air
1000-1150° Draw

Brass Extrusion Dies -

2100°F(packed) Air
1200-1250° Draw
Brinell 285-302(Before Machining)

Brass Extrusion Dies -

2200°F(packed) Air
1300 Draw
Brinell 285-302
Rockwell C 42-45

Hot Press Dies, Axle Flange

2150°F Air
1290 Draw C 46

TYPE 2

Hot Press Punches, Axle Flange

2150°F	Oil	
1250	Draw	C 40

Coining Dies, Upsetting

2150°F	Air (packed)	
1200	Draw	C 46–48

TYPE 2

Dilatometric Observation:

Analysis:

C	-	.53
Mn	-	.14
Si	-	.15
Cr	-	3.87
Va	-	.98
W	-	18.29

The analysis of this steel is not unlike that of Type 1, but the critical transformations exhibit a marked constitutional difference.

The heating was carried to 900°C and showed a critical transformation (Ac) at 790° - 840°C. Sufficient time and temperature were given after this transformation to ensure complete solution of carbides.

Cooling was started slowly and two critical points were recorded; Ar_1 - 800°-700°C and Ar_2 - 350°-250°C. It will be observed that opposite to Type 1

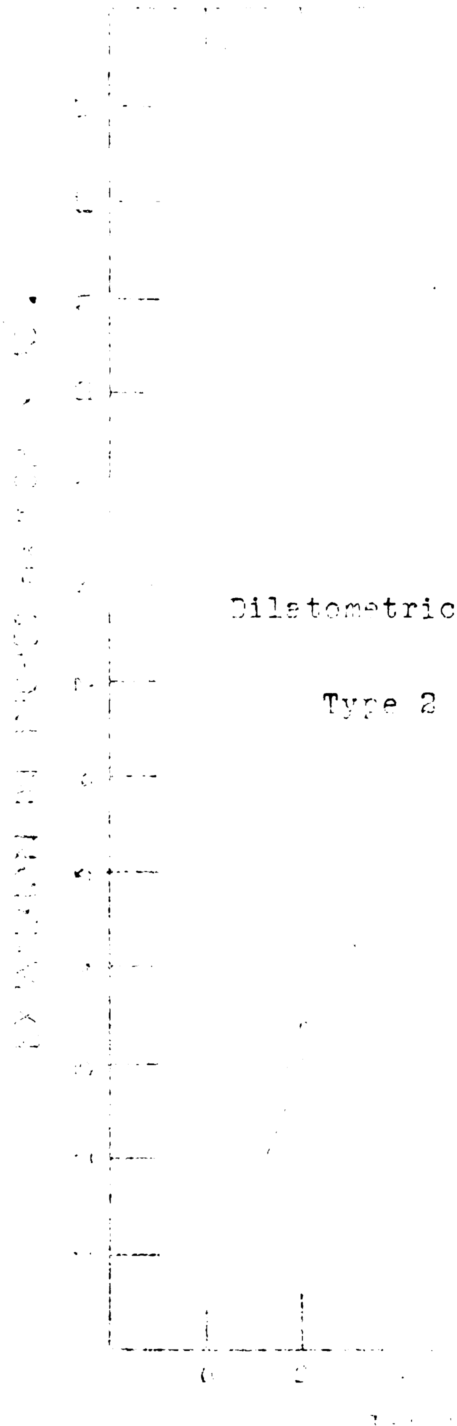
TYPE 2

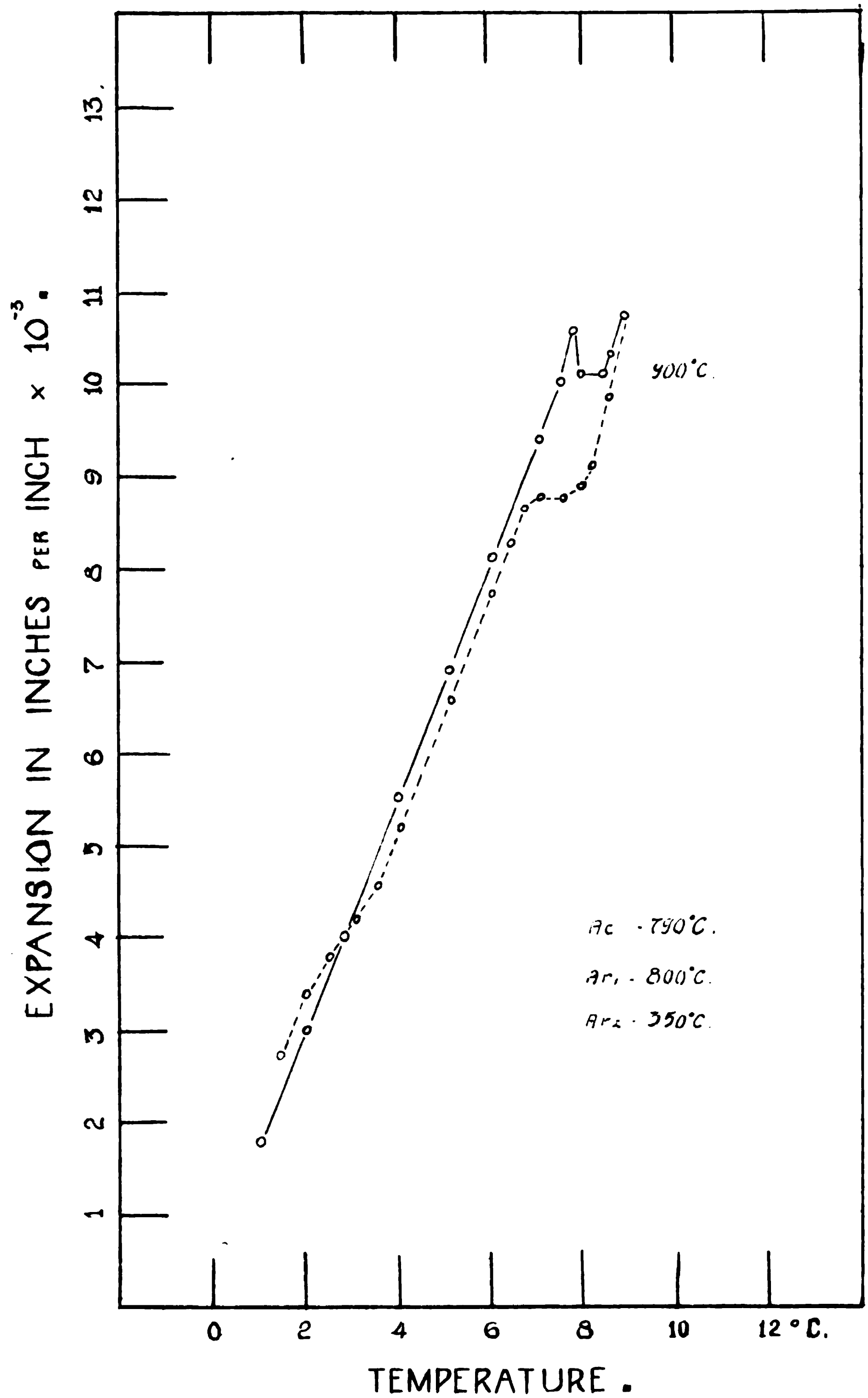
Dilatometric Observation (contd)

the Ar_1 point in this steel shows the greater volume change. This condition is due to the low carbon percentage in the steel, resulting in martensite of low carbon analysis, which naturally raises the critical point. The Ar_2 point is very small, but shows considerable expansion, indicating a martensitic change.
The steel shows a slight expansion at the point where cooling was discontinued.

Dilatometric Curve

Type 2




EXPANSION IN INCHES PER INCH × 10^-3
TEMPERATURE
°C.
900°C
Ac - 790°C
Ar1 - 800°C
Ar2 - 350°C

TYPE 2

Two photomicrographs at high magnification ,(x2200) are shown.

Figure 3 is in the annealed condition and is not unlike Figure 1 of Type 1. It shows the large globules of excess alloy that has been precipitated.

Figure 4 is in the hardened condition, 2250°F Oil, and like Figure 2 shows an austenitic structure with excess tungsten carbide globules but failed to go into solution.

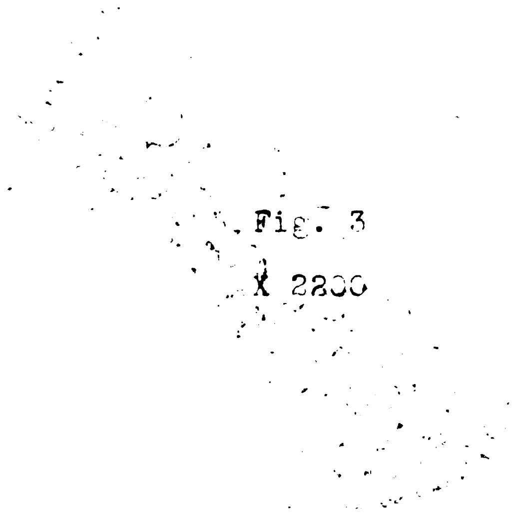


Fig. 3

X 2800

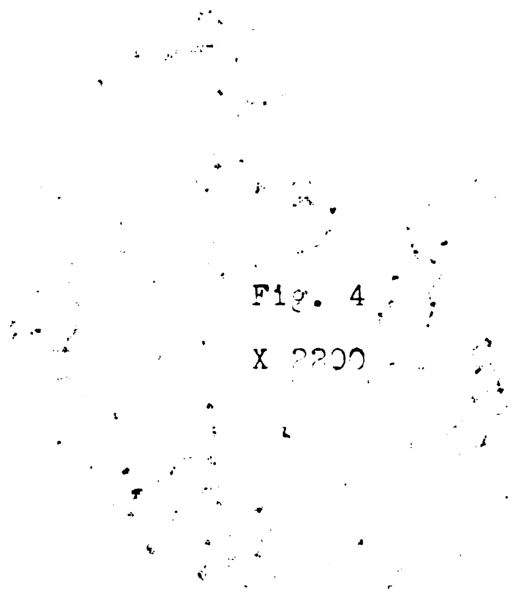


Fig. 4

X 2800

TYPE 3

Analysis:

C	-	.50-55
Mn	-	.15-30
Si	-	.15-30
Cr	-	3.75-4.25
Va	-	.85-1.00
W	-	17.50-18.5
Co	-	4.00- 4.5
Mo	-	.75- 1.0

This type is similar chemically to the regular 18:4:1 analysis with the addition of approximately 4% cobalt and 1% molybdenum.

At first it was thought that this analysis gave greater resistance to erosion at elevated temperatures. There are many drawbacks and disadvantages with this type of analysis. The first and foremost is the lack of uniformity of results obtained in practice; second, the marked tendency to develop a decarburized case at 2250°F, which rapidly increases up to 2400°F.

It is safe to say that there is no hot work application that cannot be done equally as well, or perhaps better, with Type 2 analysis previously described. Some very phenomenal results have been obtained with Type 3 steel in extruding hard non-ferrous alloys such as brass, but owing to lack of uniformity, it does not average over a long period of time as well as other compositions.

TYPE 3

Heat Treatment:

Forging	-	1850 - 2000°F
Annealing	-	1550 - 1600°
Brinell	-	235 - 255

Rockwell Hardness after Oil and Air Cooling:

	2100°F	2250°F	2300°F
No Draw	C 54	C 55	C 58
1000	54	55	58
1100	52	55	58
1200	44	54	57
1250	38	50	51
1300	33	48	49

Recommended Hardening Treatment:

Preheat	-	1500°F.
Quench	-	2000° - -2150°F (packed) Air
Draw	-	(According to hardness desired)

TYPE 3

Tensile Properties - At Elevated Temperatures

Temperatures, 900°, 900° and 1100°F respectively.

Tensile Strength lb/SqIn.	Yield Strength lb/SqIn.	Elongation %	Red of Area %	Rockwell Hardness	Heat Treatment
146,170	-	5.0	13.4	C 41	2100° Air 1300 Draw
191,520	-	0	0	49	2250° Air 1200 Draw
128,030	-	9.0	18.8	43	2250° Air 1350 Draw

Typical Uses - Hot Work

Extrusion Dies - Brass,	2100°F Air (packed) 1300 Draw Rockwell C 42-44
Gripper Dies,	2150°F Air (packed) 1250 Draw Rockwell C 42-45

TYPE 4

Analysis:

C	-	.30 -	.35
Mn	-	.15 -	.30
Si	-	.20 -	.35
Cr	-	3.00 -	3.50
Va	-	.30 -	.50
W	-	10.00 -	12.00

This type of steel is probably more widely used for hot work purposes than any other analysis so far developed. The analysis differs widely for different consumers and manufacturers, but they are all fundamentally the same basic type. The most common range is given in the analysis chart. However, it is common to have the chromium 3.0/8.0% and the tungsten 6.0/14.0%; the carbon of course will vary between .30/45% with these elements,- the higher the alloying elements the lower the carbon content. For example the C - .40/45, Cr -6.0, W - 6.0 type is quite commonly used.

This steel presents much ease and latitude in heat treating, and can be quenched in air or oil with equally good results. It is to be noted that with a very high penetration hardness, this steel has a very high yield point, and shows considerable ductility with a reduction of area of 14.0%.

The heat resistance - as shown in tempering chart - is exceptionally good. The breakdown in hardness is very gradual even at temperatures as high as 1200°F. It is not susceptible to brittleness with impact or heat checking when properly hardened.

TYPE 4

Heat Treatment:

Forging	-	1750°	-	1900°F
Annealing	-	1550°	-	1600°
Brinell	-	207	-	228

Rockwell Hardness after Oil or Air Cooling:

	1950°F	2150°F	2250°F
No Draw	C 48	C 52	C 56
1000	48	52	56
1050	48	52	56
1100	48	52	54
1150	46	51	53
1200	44	47	46
1250	35	43	45
1300	29	38	39

Recommended Hardening Treatment:

Preheat	--1500°F
Quench	- 2150° - 2250°F Air or Oil.
Draw	- According to hardness desired.

TYPE 4

Charpy Impact Values in Foot Pounds.

Analysis:

C	-	.36
Cr	-	3.22
Va	-	.44
W	-	10.63

Heat Treatment:

Quench	Temp. °F.	Draw °F	Charpy Values	Rockwell Hardness
Air	2150	1200	8.43	C 60
Oil	1950	1225	13.05	28
"	2050	1200	9.32	47
"	2150	1100	3.29	53
"	2150	1200	5.86	48
"	2300	1200	2.62	54

TYPE 4

Tensile Properties - At Room Temperature

Analysis:

C - .38

Cr - 3.25

Va - .39

W - 10.73

Tensile Strength lb/SqIn.	Yield Strength lb/SqIn.	Elongation %	Red of Area %	Hardness Rock.	Hardness Shore	Heat Treatment
252,370	222,000	6.15	13.8	C 49	62	2050°F Oil 1180 Draw

At Elevated Temperatures

75°, 700°, 900°, and 1100°F respectively.

247,390	210,000	9.0	31.7	C 48	62	2150°F Oil 1150 Draw
208,770	186,000	10.0	32.1	-	-	" "
185,540	167,560	11.0	31.7	-	-	" "
144,515	128,500	12.0	19.8	-	-	" "

TYPE 4

Typical Uses - Hot Work

Brass Forming Dies,

2150°F Oil
1200 Draw C 45-48

Aluminium Extrusion Dies,

2150°F Oil
1180 Draw C 48

1270 Draw C 36-42
(Before Machining)

Sizing Ring Steel .40% Carbon,

2100°F Air
1250 Draw C 40
(Before Machining)

Gripper Dies - Upsetting Pivots,

2100°F Air
1250 Draw C 40

Insert Dies - Ford Valves

2150°F Oil
1150 Draw C 48-50

Rotary Shears - Skelp Mill,

2150°F Air
1225 Draw C 42

Forming Dies - Boiler Shop,

2100°F Air
1200 Draw C 46

TYPE 4

Typical Uses (contd.)

Extruding Brass - Rods,

2250°F	Air	
1100	Draw	C 42-45

Extruding Brass - Sections,

2250°F	Air	
1175	Draw	C 40-42

Hot Shears - Morgan Flying Shear 2" Billets,

2150°F	Air	
1250	Draw	C 41

Hot Shears - Morgan Flying Shear- Sheet Bar,

2150°F	Air	
1250	Draw	C 41

TYPE 4

Dilatometric Observation

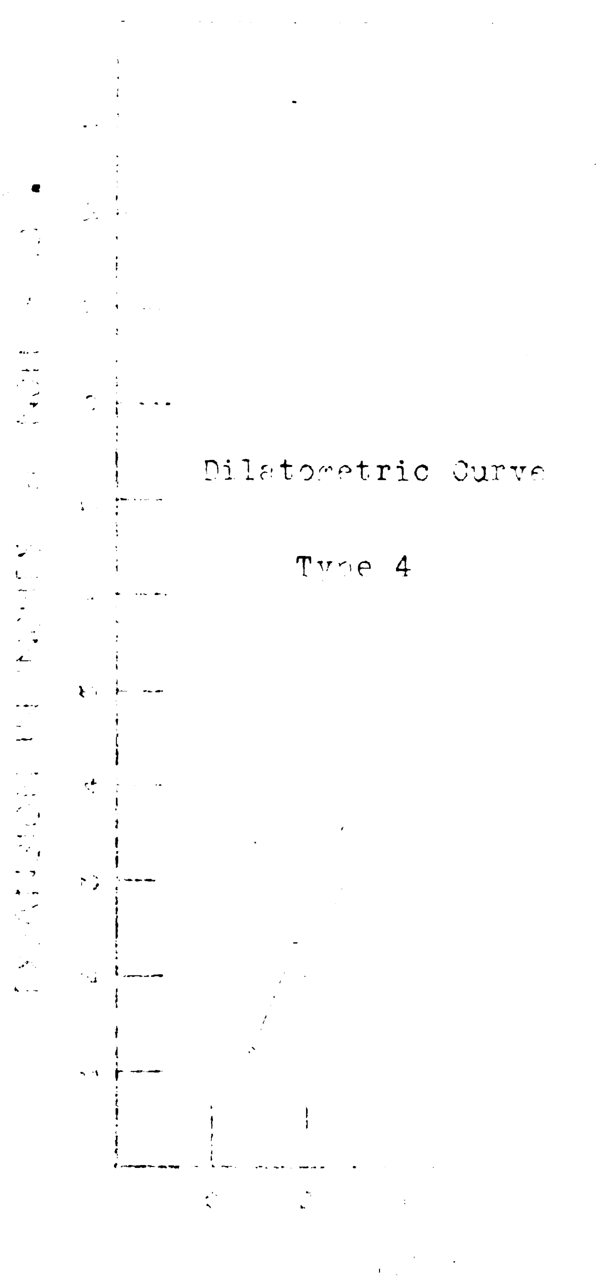
Analysis:

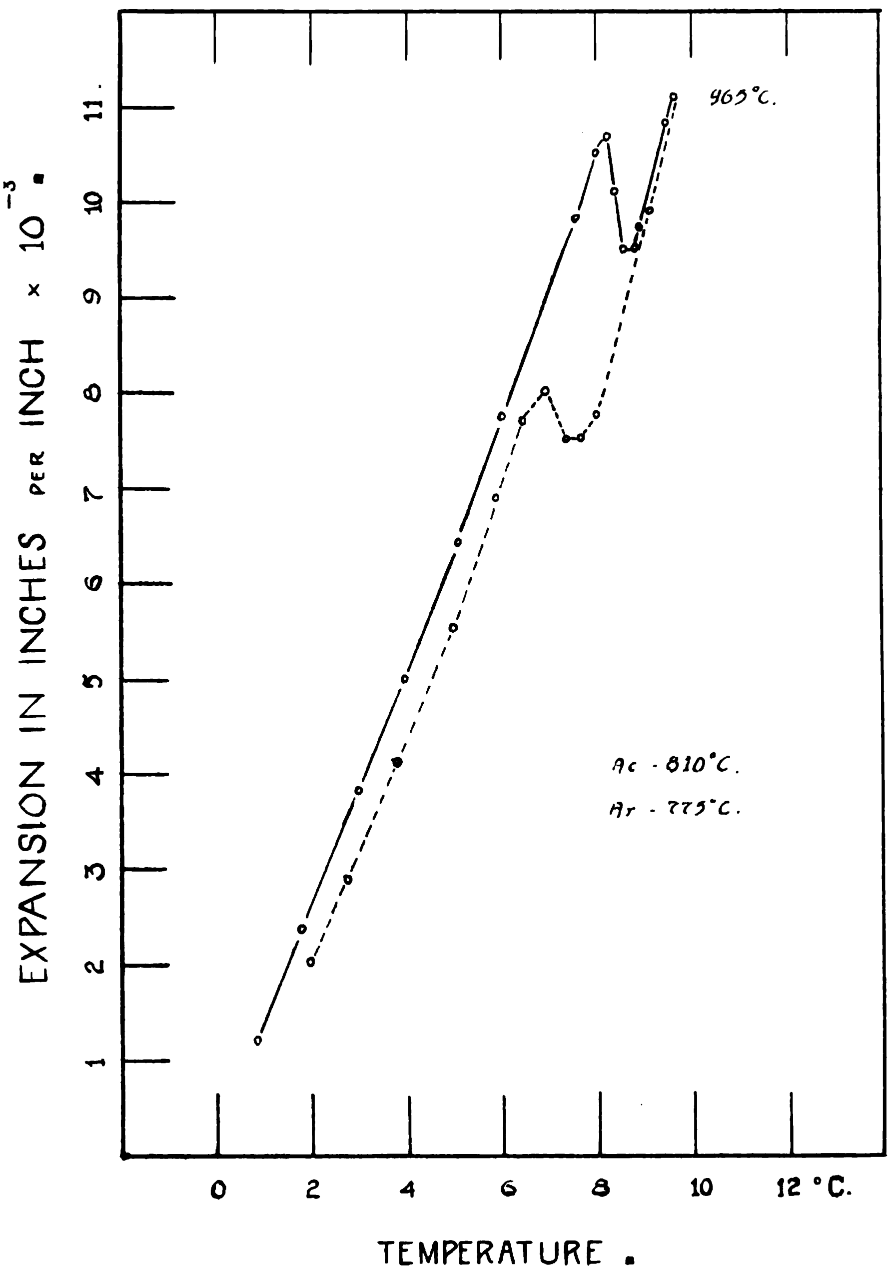
C	-	.36
Mn	-	.16
Si	-	.19
Cr	-	3.19
Va	-	.42
W	-	10.15

Two exceptionally well difinde points of considerable intensity are shown, - Ac - 810°-860°C and Ar - 775°-690°C. The intensity of the point on heating is slightly greater than the cooling transformation.

It is to be noted that the Ar transformation of this steel occurs at a much higher temperature than is usual for high tungsten steels. This is due to the low carbon contained in the precipitated martensite, the steel only containing .36% carbon originally.

The shrinkage shown where cooling was discontinued is very slight, and would be entirely removed if test specimen had been cooled to atmospheric temperature.


Dilatometric Curve
Type 4



EXPANSION IN INCHES PER INCH × 10^-3
1
2
3
4
5
6
7
8
9
10
11
965°C.
Ac - 810°C.
Ar - 775°C.
0
2
4
6
8
10
12 °C.
TEMPERATURE

TYPE 4

Two photomicrographs at 2200 diameters magnification are shown.

Figure 5 shows the steel in the annealed condition abd in contrast to the previous high tungsten types the precipitated tungsten carbides are small and somewhat spherodized.

Figure 6 shows the steel in the hardened, 2150°F-Oil, state. It shows a very peculiar structure. There are a few globules that fail to go into solution, but the excess constituents have the appearance of a laminated structure mostly radiating from a small globule. Parts of it look acicular in nature, somewhat resembling a martensitic structure.

Fig. 5

X 2200

Fig. 6

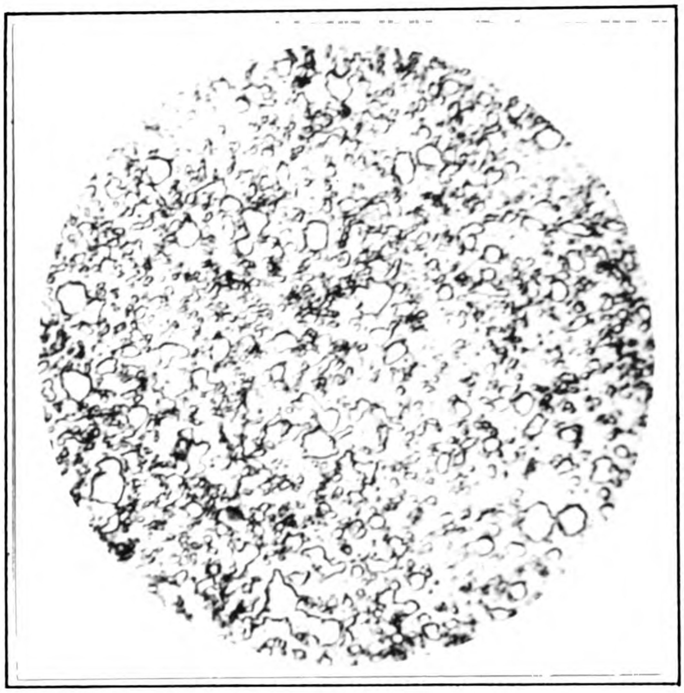
X 2200

. 17

X

. 17

X



TYPE 5

Analysis:

C	.90 - 1.05
Mn	.20 - .40
Si	.25 - .40
Cr	3.50 - 4.50

For many years this chromium type of analysis found greater hot work application than any other analysis. Even today it has a very wide application, and for many purposes serves admirably. With its fairly high percentage of chromium, it withstands the breaking down of the hard martensite at reasonably high temperatures. It is able to withstand temperatures up to 900°F. for a reasonable length of time without softening, but above this temperature, or where contact with heat is excessively long, softening occurs.

A considerable tonnage of this grade goes into bolt and riveting machines for header dies, also hot forging mandrels.

The simplicity of heat treating is a very desirable feature, as well as the cost.

TYPE 5

Heat Treatment:

Forging - 1750°-1800°F

Annealing- 1450°-1500°

Brinell - 196 - 207

Rockwell Hardness after Oil and Air Cooling:

	1850°F Air	1600°F Oil
No Draw	C 54	C 61
600°F	53	55
800	52	53
1000	49	48
1050	47	47
1100	40	45
1150	38	41
1200	35	40

Recommended Hardening Treatment:

Quench - 1825 - 1875°F

Draw - 900 - 1000° (or to hardness desired)

TYPE 5

Analysis:

C	Mn	Si	Cr
.95	.68	.25	4.0

Charpy Impact Values in Foot Pounds

Quench	Heat Treatment Temp. °F	Draw	Charpy Values	Rockwell Hardness
Air	1850	-	3.96	C 54
Oil	1600	350	4.66	54
Oil	1600	1000	14.91	48

Tensile Properties - At Room Temperature

Tensile Strength lb/SqIn.	Yield Strength lb/SqIn.	Elongation %	Red of Area %	Hardness Rock.	Hardness Shore	Heat Treatment
223,780	143,000	7.36	20.7	C 38	50	1850°F Air 1100 Draw
270,850	222,000	2.73	1.7	48	64	1550°F Oil 850 Draw

At Elevated Temperatures

900° and 1100°F respectively

Tensile Strength lb/SqIn.	Yield Strength lb/SqIn.	Elongation %	Red of Area %	Hardness Rock.	Hardness Shore	Heat Treatment
181,680	-	13.0	49.2	C 43	-	1850°F Air 1100 Draw
120,280	-	23.0	64.7	43	-	1850°F Air 1100 Draw

TYPE 5

Typical Uses - Hot Work

Gripper Dies, Rivets

1850°F	Air	
1050	Draw	Shore 60-65

Header Dies, Bolts

1850°F	Air	
1050	Draw	Shore 60-65

Gripper Dies, Bolts

1850°F	Air	
800	Draw	Shore 65-70

TYPE 5

Dilatometric Observation:

Analysis:

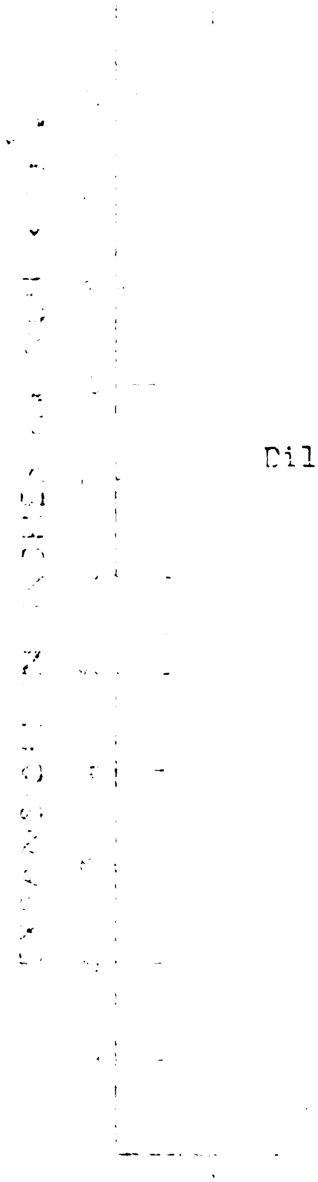
C	-	.94
Mn	-	.60
Si	-	.39
Cr	-	4.05

The curve resulting from this steel shows two exceptionally well defined critical points,- Ac 750°-800°C. and Ar 660°- 675°C. The intensity of both critical points is very great, although both transformations are completed within a comparatively narrow temperature range.

The Ar point shows a considerable degree of expansion. This is due to the formation of the less dense martensite which, of course, has a much greater specific volume than the preceding austenitic phase.

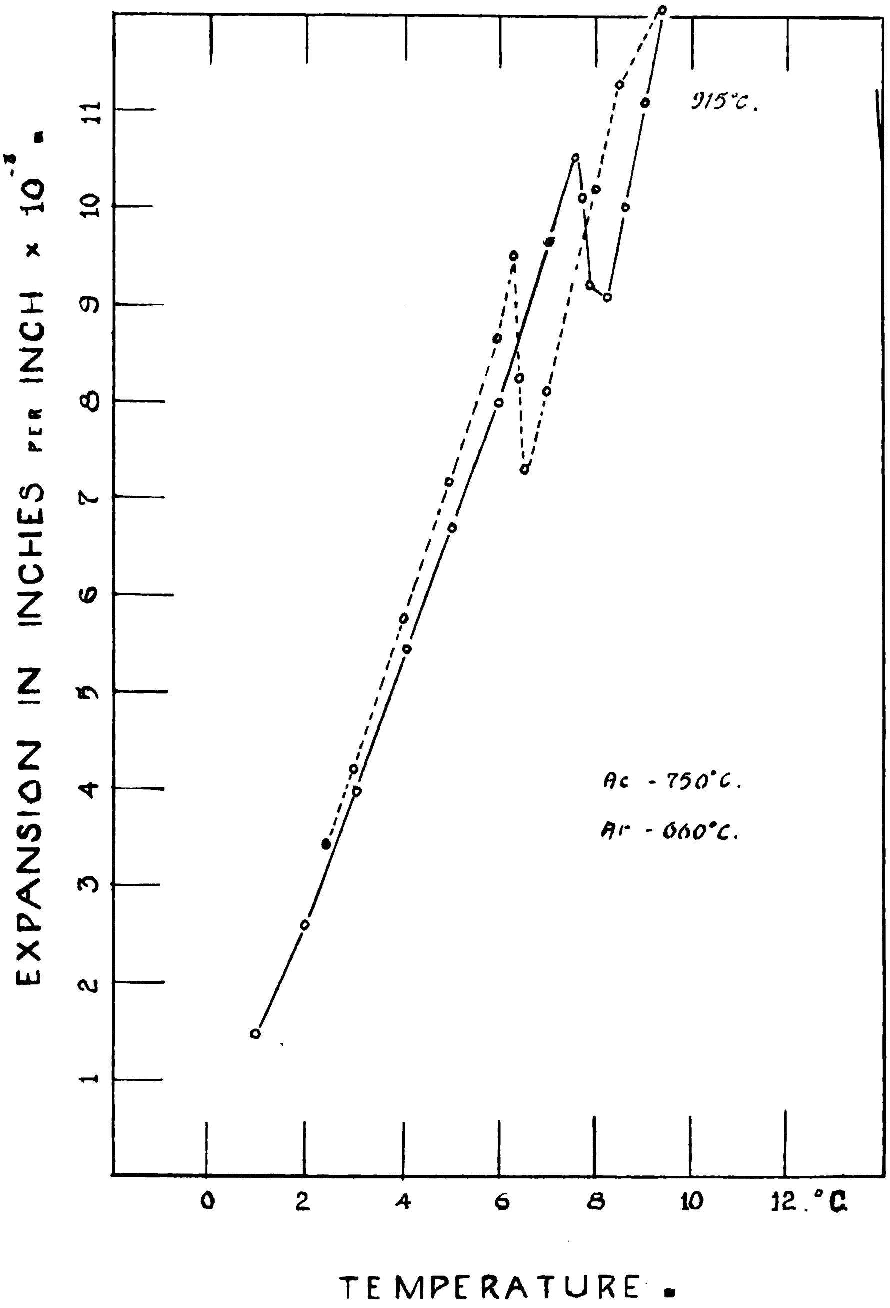
After completion of the Ar transformation the steel assumes a normal rate of cooling, with the cooling curve falling in close proximity to the heating curve.

A slight expansion of the steel is still in evidence at the point where test was discontinued, but it is very small and the chances are that had been continued to room temperature, the change of shape (expansion) would have been very slight.



Dilatometric Curve

Type 5


EXPANSION IN INCHES PER INCH × 10⁻³
1
2
3
4
5
6
7
8
9
10
11
0
2
4
6
8
10
12. °C
915°C.
Ac - 750°C.
Ar - 660°C.
TEMPERATURE.

TYPE 5

Two photomicrographs at 2200 diameters magnification are shown.

Figure 7 shows the steel in the annealed condition. It is composed of very finely precipitated chromium carbides.

Figure 8 is the hardened, 1850°F - Air, condition.

A very peculiar type of structure is shown. The austenitic grains are large and well defined, the grain boundaries are wide and very irregular. A second, or superimposed structure, can be seen clearly by varying the focus. This second structure has the appearance of fine globules that failed to go into solution,

Fig. 7

X 2200

Fig. 8

X 2200

TYPE 6

Analysis:

C	-	.40 - .50
Mn	-	.20 - .30
Si	-	.80 - 1.0
Cr	-	1.30 - 1.5
W	-	1.50 - 2.0
Va	-	.20 - .30

This type of steel has found extremely wide application; especially where any degree of shock is present. It is suitable for both hot and cold work purposes, probably finding greater use for the latter than the former purpose. It is a very highly alloyed analysis, and on a cursory view might be thought to be brittle; but the opposite is true. It is probably one of the toughest and most ductile tool steels manufactured.

There is a very large tonnage of this steel used in the form of shear blades; - hot and cold.

The analysis used in this type is nearly fool-proof in heat treatment, which is a very desirable feature. A disagreeable characteristic is the tendency to harden with a soft skin. This condition is much more pronounced when the steel is hardened in an electric furnace. In a gas fired furnace it can be controlled fairly well. When hardened in a coke forge there is no evidence of this condition. The contact with the carbonaceous material probably acts as carburizing agent. Due to this characteristic, it is advisable to pack-harden small sections, - punches, or sections that are not later to be ground. The Rockwell hardness of this steel is not a very great factor in the life of the tools.

TYPE 6

Heat Treatment:

Forging - 1650° - 1750°F

Annealing - 1450°F

Brinell - 196 - 217

Rockwell Hardness after Oil Quench:

	1700°F Oil	1750°F Oil
No Draw	C 56	C 58
700°F	53	54
900	47	50
1000	48	49
1100	47	48
1200	40	43

Recommended Hardening Treatment:

Quench - 1650° - 1750°F Oil

Draw - As desired.

TYPE 6

Charpy Impact Values in Foot Pounds

Heat Treatment Quench	Temp. °F	Draw	Charpy Values	Rockwell Hardness
Oil	1700	-	17.7	C 56
Oil	1700	450	22.0	54
Oil	1700	1050	31.3	48
Oil	1700	1200	62.1	34

Tensile Properties - At Room Temperature

Tensile Strength lb/SqIn.	Yield Strength lb/SqIn.	Elongation %	Red of Area %	Hardness Rock.	Hardness Shore	Heat Treatment
307,260	195,000	2.65	.91	C 54	69	1700°F Oil No Draw
307,730	250,000	4.51	8.81	52	69	1700°F Oil 600 Draw
287,880	238,000	4.51	6.67	51	65	1700°F Oil 750 Draw
244,880	201,000	6.67	13.30	46	60	1700°F Oil 1050 Draw

TYPE 6

Tensile Properties - At Elevated Temperatures

Temperatures, 75°, 700°, 900°, 1100°, 1150°, 900° and 1100°F respectively.

Tensile Strength lb/SqIn.	Yield Strength lb/SqIn.	Elongation %	Red of Area %	Hardness Rock.	Hardness Shore	Heat Treatment	
227,740	208,000	10.0	38.1	C 46	60	1675°F 950	Oil Draw
194,080	166,000	15.0	57.1	46	60	"	"
151,605	135,000	20.5	64.1	46	60	"	"
82,610	68,000	44.0	85.3	46	60	"	"
72,650	56,000	55.0	88.1	46	60	"	"

175,6000	-	2.0	1.2	42	-	1750°F 1250	Oil Draw
145,020	-	6.0	14.8	"	-	"	"

Analysis Used For Charpy And Tensile Tests: (not including last two tensiles)

C	Mn	Si	Cr	Va	W
.46	.29	.96	1.45	.29	2.00

TYPE 6

Typical Uses - Hot Work

Aluminium Extrusion Dies,

1750°F	Oil	
1250	Draw	C 36-37 (Before Machining)

Aluminium Extrusion Dies,

1750°F	Oil	
975	Draw	Shore 63-68

Header Rivets,

1750°F	Oil	
1150	Draw	Shore 55-60

Shear Knives - Bar Mill,

1750oF	Oil	
550	Draw	Shore 65-67

Aluminium Die Castings,

1750°F	Oil	
1050	Draw	Brinell 444

Bull Riveter,

1750°F	Oil	
1225	Draw	Shore 50-55

Shear Knives - Rotary Hot Mills 3/16" thick,

1750°F	Oil	
450	Draw	Shore 72-77

TYPE 6

Typical Uses (contd)

Shear Knives - Billet and Bloom,

1750°F	Oil	
1050	Draw	Shore 60

Shear Knives 9" Blooms,

1750°F	Oil	
1250	Draw	Shore 55

Dummy Blocks - Extrusion of Brass,

1750°F	Oil	
1100	Draw	C 42-44

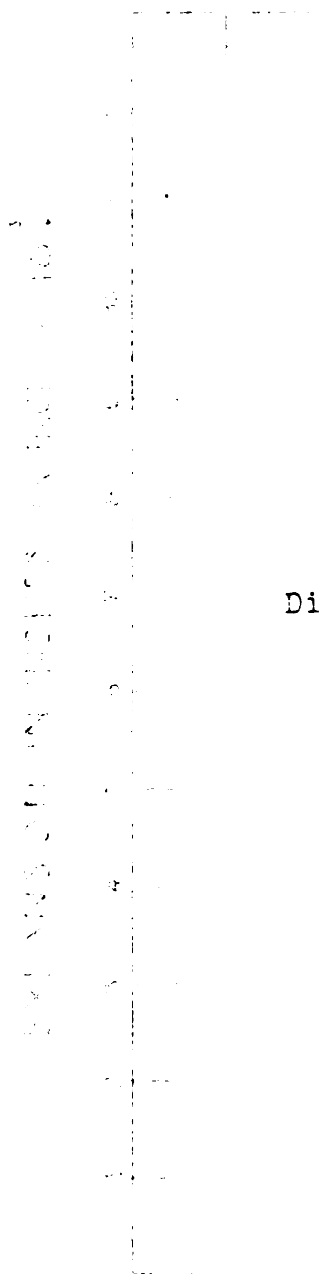
TYPE 6

Dilatometric Observation

Analysis:

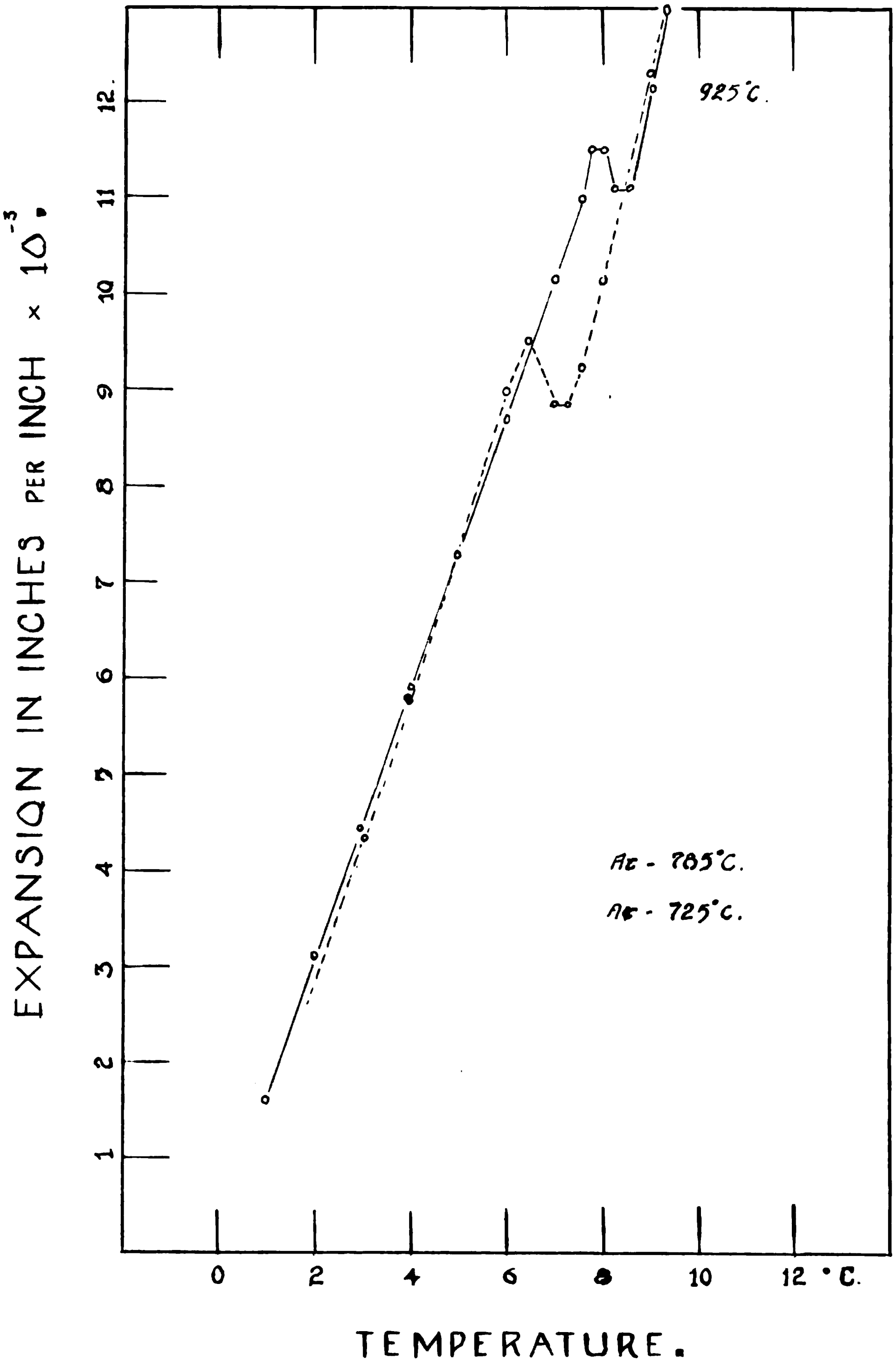
C	-	.47
Mn	-	.29
Si	-	.92
Cr	-	1.22
Va	-	.23
W	-	1.90

This curve shows a well defined Ac critical point at 785° - 850°C, with the Ar point at 725° - 680°C equally well defined and of about the same intensity. The noticeable thing about this curve is how quickly and closely it returns to normal dimensions after the completion of the Ar transformation. Being an oil hardening steel accounts for some of the lack of distortion, but the analysis is such as to eliminate any great amount of movement in the steel.



Dilatometric Curve

Type 6



EXPANSION IN INCHES PER INCH × 10⁻³
1
2
3
4
5
6
7
8
9
10
11
12.
925°C.
785°C.
725°C.
0
2
4
6
8
10
12 °C.
TEMPERATURE.

TYPE 6

Two photomicrographs, showing this steel annealed and hardened, are shown at 2200 diameters magnification.

Figure 9 shows the annealed structure of the steel. It is a normal structure for a complex alloy such as this steel.

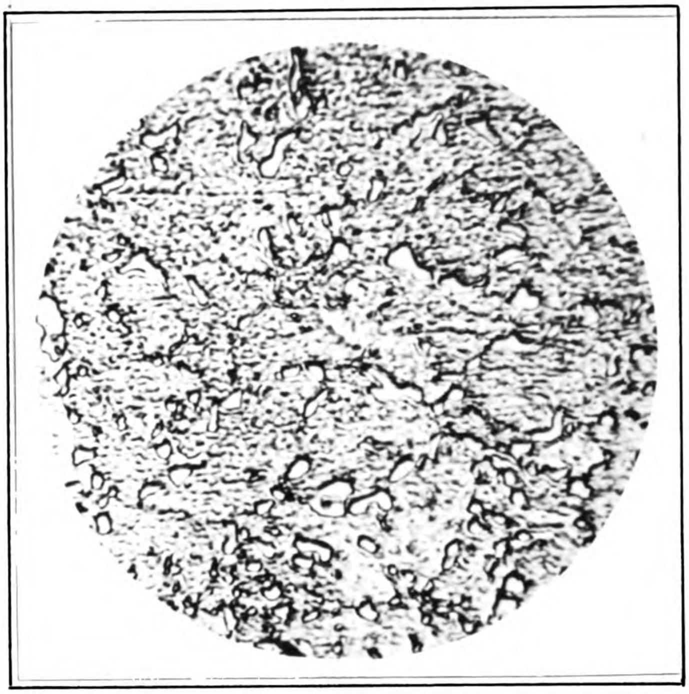
Figure 10 is hardened, 1750°F - Oil, structure and shows the rejected excess constituents in a decided laminated or banded condition.

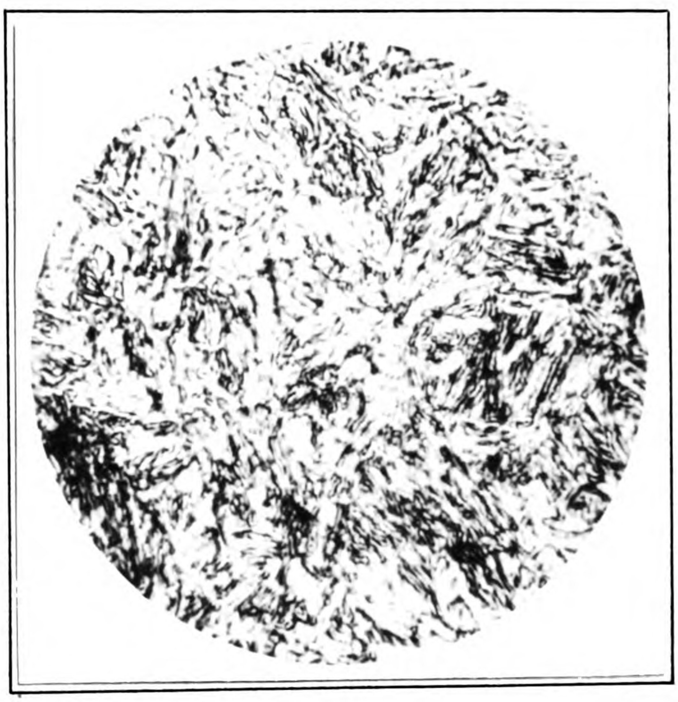
Fig. 9

X 2200

Fig. 10

X 2200





TYPE 7 and 8

Analysis:

	Type 7	Type 8
C -	.30 - .40	.45 - .50
Si -	.80 - 1.00	.30 - .50
Cr -	4.75 - 6.00	4.25 - 4.75
Va -	.20 - .30	.20 - .30
W -	4.75 - 6.00	1.75 - 2.00
Co -	.40 - .60	- - -
Mo -	.15 - .30	.85 - 1.00

This type of steel was developed primarily for the non-ferrous industry. It found its first application in pressure die casting the hard aluminum alloys. It proved much superior for this type of work then anything previously used. Since that time it has found a much wider application.

This steel, although not generally considered as suitable for extruding the hard non-ferrous metals such as brass, proves very good for such work, if care is used in preparing the dies and is properly heat treated. It does not offer the same resistance to abrasion and erosion at elevated temperatures as Types 2 and 4; but it is certainly warrants use in such times as these when the volume being extruded is not great. It probably averages three-fourths the life of the high tungsten steels on this work.

TYPE 7 and 8

This steel offers great ease in heat treating, - being air hardening, and shows little or no tendency to scale with a minimum of warpage.

It withstands breakdown from heat up to 1100°F, before any sudden change of hardness is apparent.

TYPE 7

Heat Treatment:

Forging	-	1900° - $2000^{\circ}F$
Annealing	-	1550° - 1600°
Brinell	-	217 - 235

Rockwell After Oil and Air Cooling:

	$1825^{\circ}F$
No Draw	C 55
800°	55
900	55
1000	54
1050	52
1100	49
1200	40

Recommended Hardening Treatment:

Quench - 1800°-$1850^{\circ}F$ (Air)
Pack Harden.

Draw - 900°-$1100^{\circ}F$
(According to hardness desired)

TYPE 7

Analysis Used On Following Charpy And Tensile Tests:

C	-	.39
Co	-	.53
Mo	-	.22
Cr	-	4.78
Va	-	.30
W	-	5.54

Charpy Impact Values in Foot Pounds

Heat Treatment				
Quench	Temp. °F	Draw	Charpy Values	Rockwell Hardness
Air	1825	-	18.90	C 55
"	1825	1000	18.90	54
"	1825	1100	19.46	49
"	1825	1200	30.67	40
Oil	1825	1000	18.90	54

TYPE 7

Tensile Properties - At Room Temperature

Tensile Strength lb/SqIn.	Yield Strength lb/SqIn.	Elongation %	Red of Area %	Hardness Rock.	Hardness Shore	Heat Treatment
259,390	217,000	8.43	17.8	C 49	62	1825°F Air 1000 Draw
161,460	126,000	13.50	37.3	35	46	1825°F Air 1150 Draw

At Elevated Temperatures

Temperatures, 75°, 700°, 900°, 1100° and 1100°F respectively.

269,470	207,000	5.0	8.6	50	67	1825°F Air 1100 Draw
241,115	192,500	9.4	25.0	-	-	" "
217,045	172,000	10.0	30.5	-	-	" "
112,950	85,000	23.8	69.9	-	-	" "

196,550	-	11.0	41.9	50	67	1825°F Air 1100 Draw

TYPE 7

Typical Uses - Hot Work

Aluminum Die Casting,

1825°F	Air	
1100	Draw	Brinell 444

Shear Blades - Rotary Sheet Bar,

1825°F	Air	
1050	Draw	C 52

Shear Blades - 35" Blooming Mill,

1825°F	Air	
1150	Draw	Shore 60

Aluminum Extrusion Dies,

1825°F	Air	
1100	Draw	Shore 65
1200	Draw	C 38-40 (Before Machining)

Brass Extrusion Dies,

1850°F Air
1150-1175 Draw C 40

TYPE 8

Dilatometric Observation

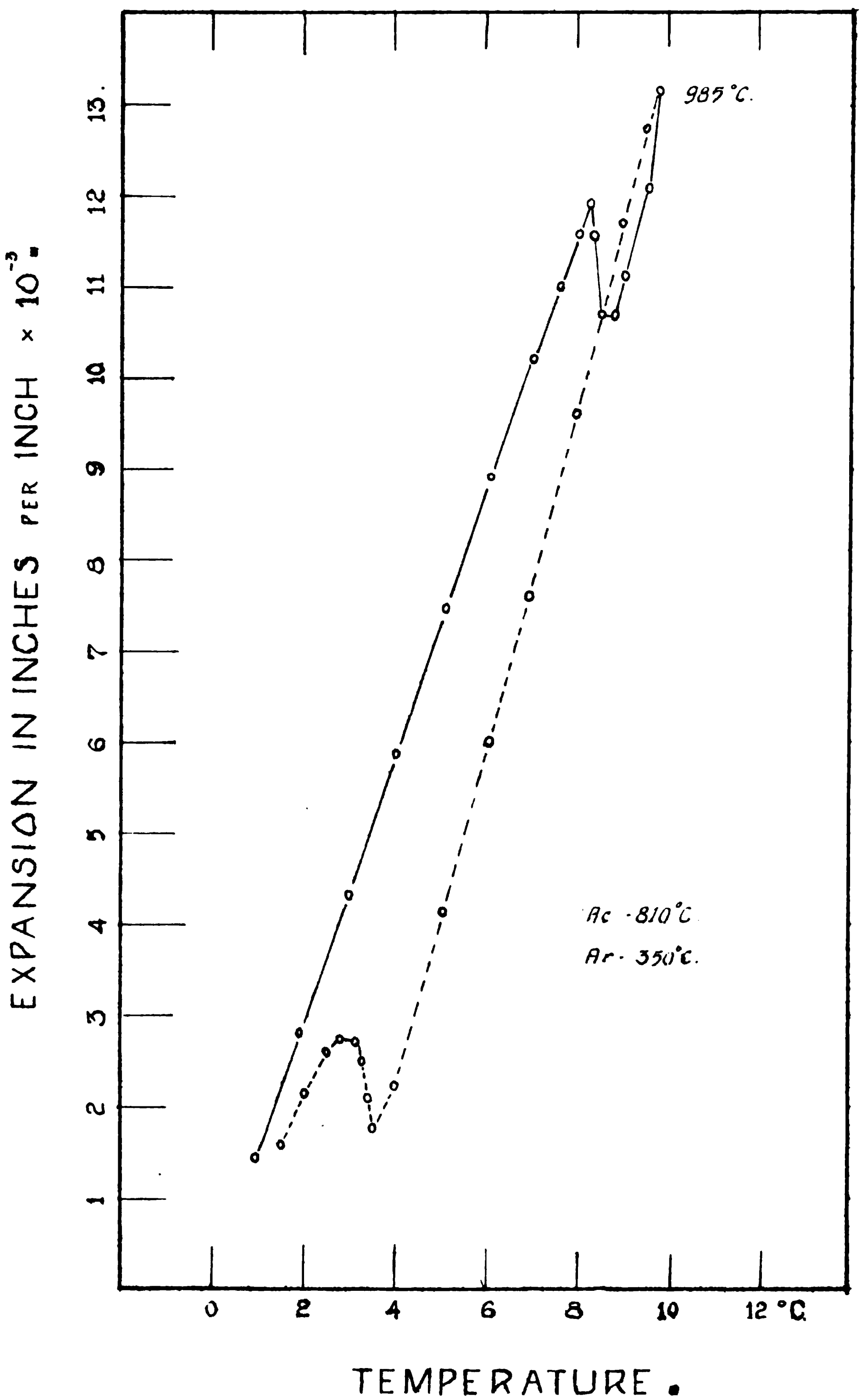
Analysis:

C	-	.39
Mn	-	.21
Si	-	.97
Cr	-	4.78
Va	-	.30
W	-	5.54
Co	-	.53
Mo	-	.22

This curve shows two well defined transformations; Ac, 810° - 870°C and Ar, 350° - 300°C. Both transformations are of considerable magnitude and about the same intensity.

At the point where cooling was discontinued the specimen showed a small amount of shrinkage, but nothing very great, and it is quite likely that had cooling continued to room temperature, the heating and cooling curves would have closely approached each other.


Dilatometric Curve
Type 7



985 °C.
Ac - 810°C
Ar - 350°C.
EXPANSION IN INCHES PER INCH × 10^{-3}
1 2 3 4 5 6 7 8 9 10 11 12 13.
0 2 4 6 8 10 12 °C
TEMPERATURE

TYPE 7

Two photomicrographs, annealed and hardened, are shown at 2200 diameters magnification.

Figure 11 shows the annealed structure. The highly alloyed nature of this steel is clearly shown.

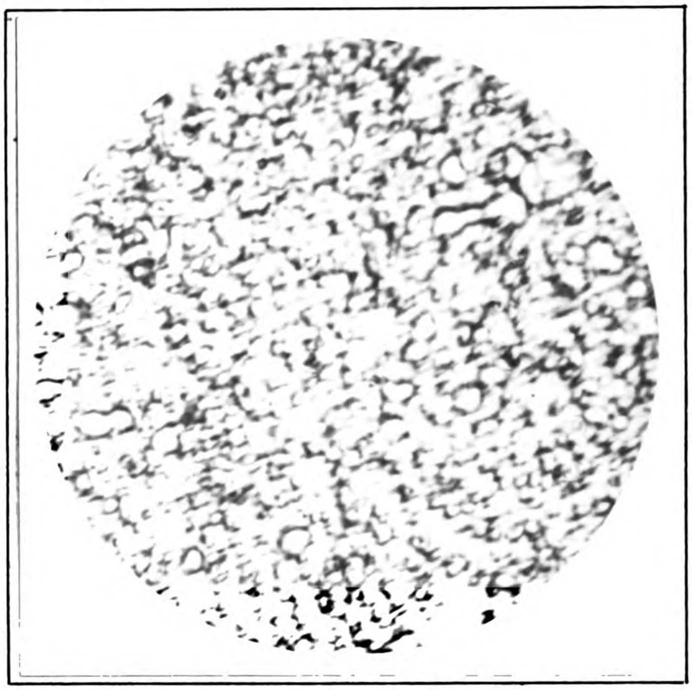
Figure 12 is the hardened, 1825°F Air, structure. The picture is slightly out of focus, but shows a large excess of precipated compounds in globular form that have failed to go into solution.

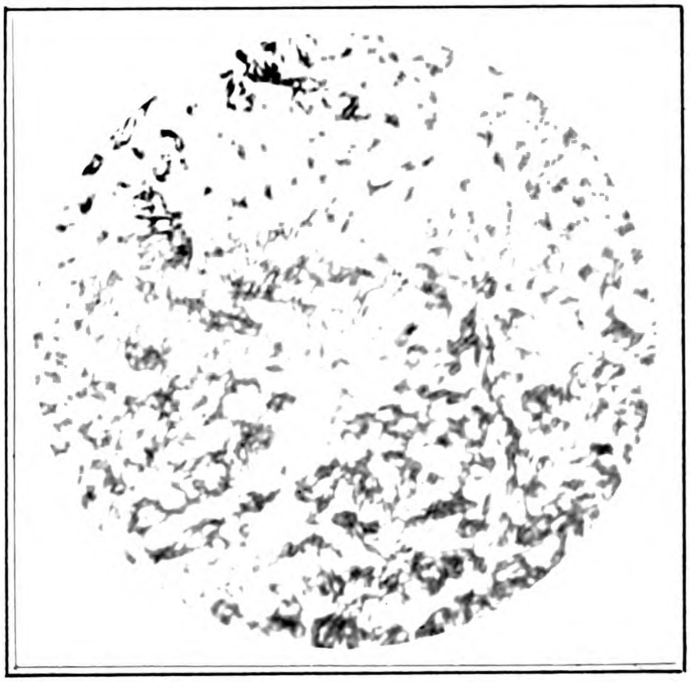
Fig. 11

X 2200

Fig. 12

X 2200





TYPE 9

Analysis:

C	-	.35	-	.45
Si	-	.20	-	.35
Cr	-	6.00	-	7.00
Va	-	.30	-	.50
W	-	6.00	-	7.00

This type of steel is not unlike Type 4 and is really one of its off-spring. It is used for similar purposes to the older and higher tungsten type. There are few, if any, applications where Type 4 will not do equally as well, or perhaps better. The results obtained from Type 4 seem, over a long period of time, to be more consistent and dependable.

It will be noted that the carbon is somewhat higher than in Type 4.

The treatment of these two steels is just about the same.

TYPE 9

Heat Treatment:

Forging	-	1850°-2000°F
Annealing	-	1550°-1600°
Brinell	-	228 - 241

Rockwell after Oil and Air Cooling:

	2000°F	2150°F	2200°F
No Draw	C 56	C 61	C 62
1000°	57	61	62
1100	53	60	60
1150	51	58	58
1200	44	49	50
1250	40	45	45
1300	39	44	45

Recommended Hardening Treatment:

Preheat	-	1500°F
Quench	-	2100° - 2200°F Air or Oil
Draw	-	According to hardness desired

TYPE 9

Charpy Impact Values in Foot Pounds

Heat Treatment Quench	Temp. °F	Draw	Charpy Values	Rockwell Hardness
Oil	2000	1200	11.26	C 44
Oil	2150	*	2.32	61
Oil	2150	1100	2.90	60
Oil	2150	1200	8.84	50
Air	2150	1200	8.43	49
Oil	2300	1200	5.03	-

Tensile Properties - At Elevated Temperatures

Temperatures, 900° and 1100°F respectively.

Tensile Strength lb/SqIn.	Yield Strength lb/SqIn.	Elongation %	Red of Area %	Rockwell Hardness	Heat Treatment
153,100	-	11.0	28.5	C 43	2150°F Air 1250 Draw
129,430	-	14.5	39.1	48	2150°F Air 1200 Draw

TYPE 9

Typical Uses - Hot Work

Aluminum Extrusion Dies,

2150°F	Oil	
1180	Draw	C 49

Aluminum Extrusion Dies,

2050°F	Air	
1275	Draw	C 40-42 (Before Machining)

Pick Dies,

2150°F	Air	
1200	Draw	C 48

TYPE 12

Analysis:

C	-	.40 - .50
Mn	-	.50 - .70
Si	-	.20 - .35
Cr	-	2.50 - 3.0

This type of steel deserves mention on account of its application in die casting aluminum pistons in permenent core moulds.

It is used in the normalized and annealed condition without hardening. This treatment gives a much longer life than when the cores are hardened to any extent.

In the normalized - annealed condition over 100,000 pistons is a common run for the cores, whereas when even slightly hardened, the life of the cores is reduced to less than 15,000 pistons.

TYPE 12

Heat Treatment Used for Core Moulds:

Forging	-	1900°F
Normalizing	-	1500°
Annealing	-	1600°

The fracture resulting from the above treatment appears bright and very coarse; but it is probably this coarse structure that gives the extra life when used for casting aluminum pistons.

C O N C L U S I O N S

In a theisis of this type, - that deals mainly with facts from actual tests and applications - there is little to said under this caption.

1. It is to be observed, however, that the greater the carbon percentage in highly alloyed steels, especially high tungsten, the greater the susceptibility to heat checking, cracking and brittleness. With high tungsten percentages the best results are obtained with very low carbon percentages.

2. Hardness as expressed by indentation methods, such as the Rockwell method, is not any criterion as to the ability of the steel to withstand erosion and destruction. Generally speaking the low-

Conclusions (contd)

est Rockwell hardness that will stand up against erosion at elevated temperatures gives the best results. High Rockwell hardnesses react in the same manner as high carbon percentages, namely, susceptibility to heat-checking.

3. Where much shock is involved low Rockwell figures must be used. This is best obtained by high and long draws after quenching in a manner to obtain the maximum hardness possible.

4. The use of molybdenum and nickel has been overlooked.

ROOM USE ONLY