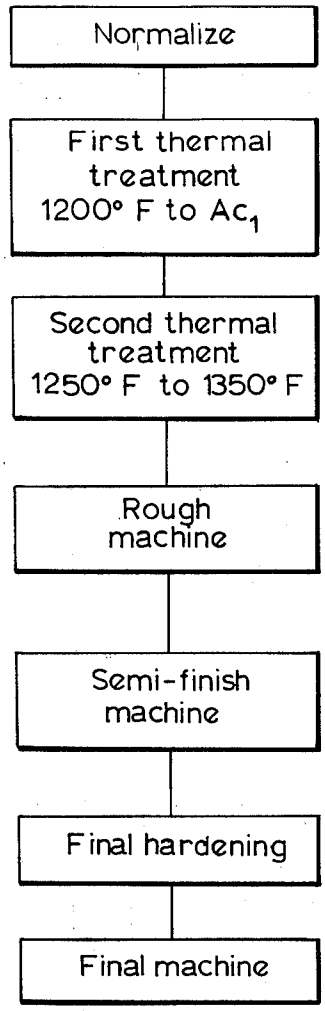
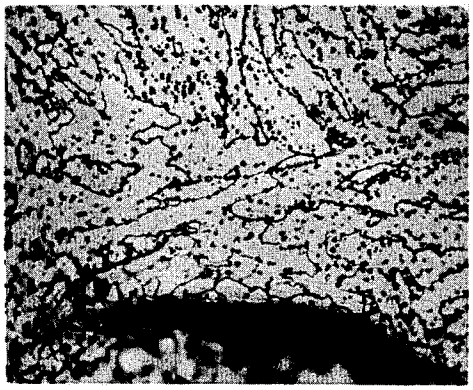


Fig. 1



1000 X

Fig. 4



1000 X

Fig. 5

Fig. 2

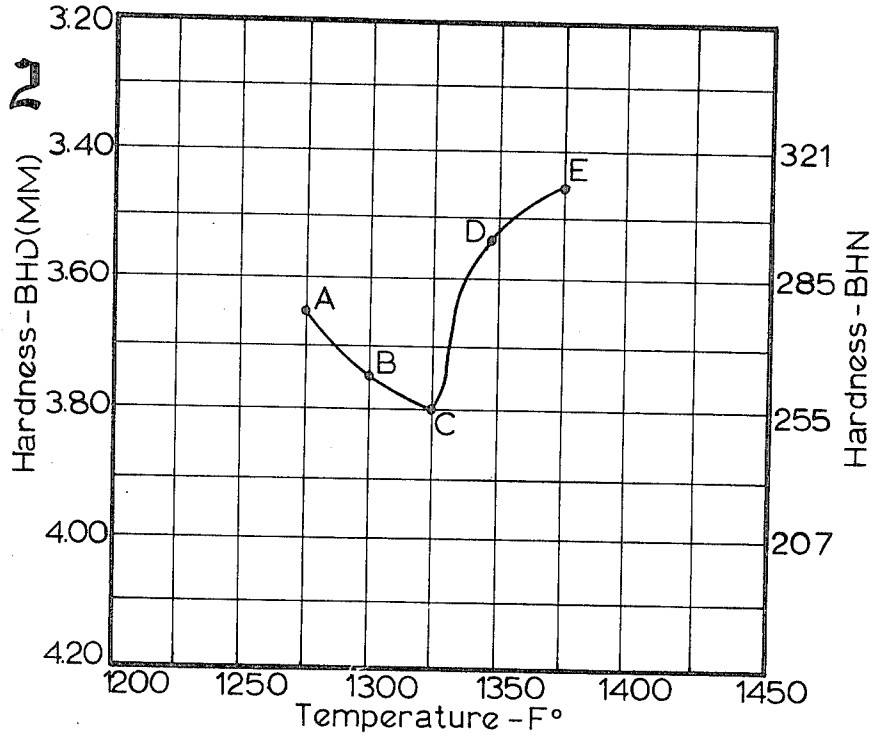
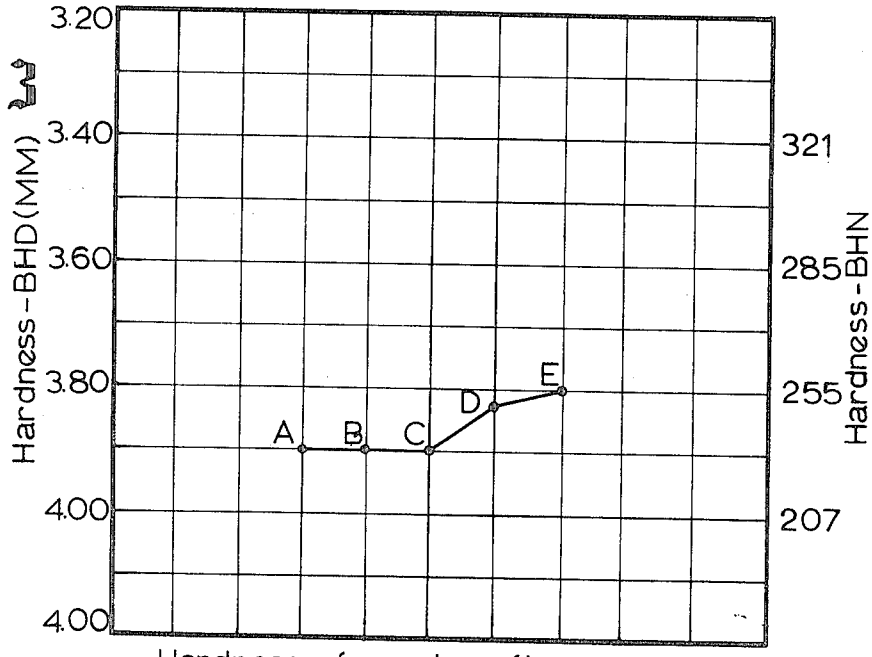


Fig. 3



Hardness of samples after second thermal treatment at 1325° F.

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May 8, 1973 R. W. FURGASON 3,732,127

METHOD OF HEAT PROCESSING ALLOY STEEL TO OBTAIN MAXIMUM SOFTNESS AND UNIFORMITY

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Fig. 8

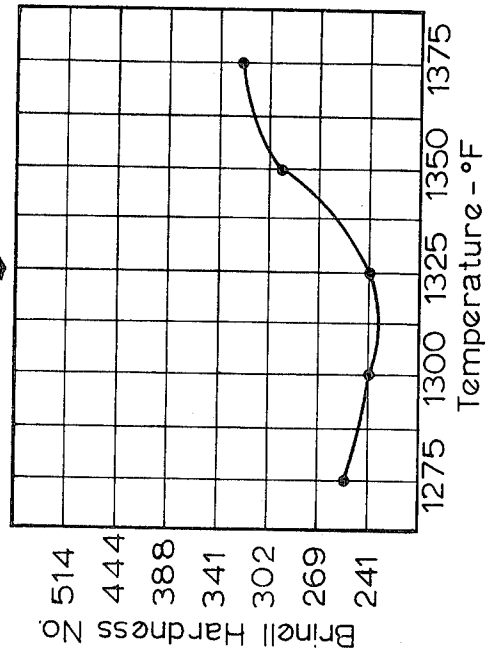


Fig. 9

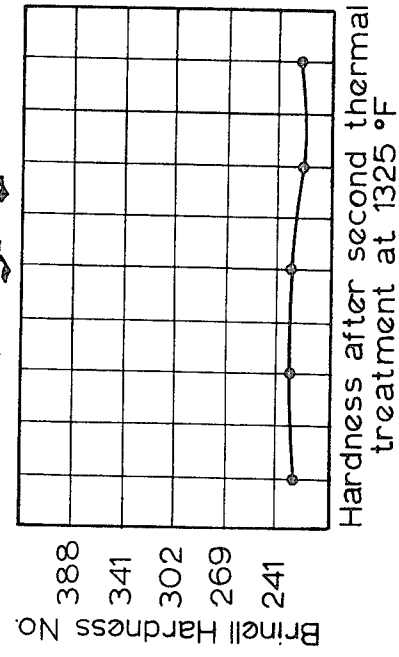


Fig. 6

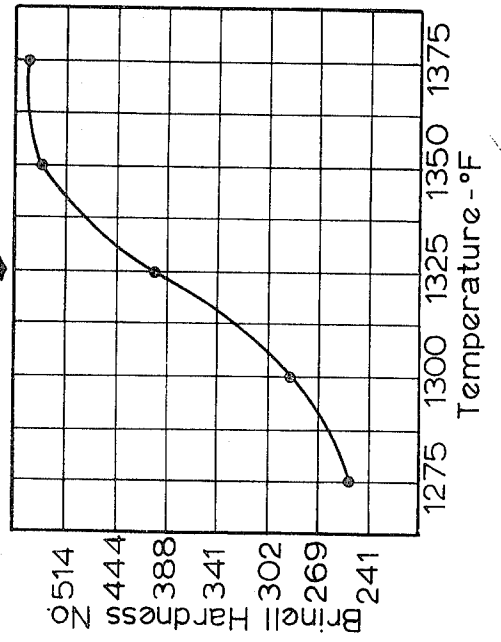
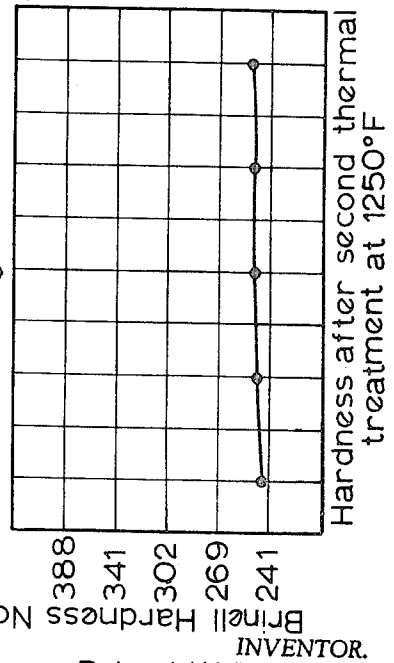


Fig. 7



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3,732,127

METHOD OF HEAT PROCESSING ALLOY STEEL TO OBTAIN MAXIMUM SOFTNESS AND UNIFORMITY

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Filed Jan. 2, 1970, Ser. No. 156
Int. Cl. C21d 1/18
U.S. Cl. 148—12.4 16 Claims

ABSTRACT OF THE DISCLOSURE

A method of thermally processing ultra high strength steel to obtain maximum softness and uniformity to increase its response to machining or other processing without adversely affecting its ability to respond to the final thermal treatment required to meet the final mechanical properties. The steel is subjected to a double thermal process in which the steel is initially given a thermal treatment at a temperature above 1200° F. and below the recognized lower critical on heating, cooled to below the martensitic finish temperature, and then reheated to a temperature in the range of 1250° F. to 1350° F. During the initial treatment the steel is maintained at temperature for a period of time sufficient to allow small areas of the steel to transform to austenite and cause the remaining carbides to spheroidize and upon cooling produces a microstructure which exhibits a partially spheroidized structure with small areas of fresh martensite uniformly dispersed throughout. The second thermal treatment causes the fresh martensite to spheroidize into carbides to provide a microstructure and low hardness level which is more responsive to further processing, as well as improved uniformity in hardness throughout the part and from part-to-part.

This invention relates to a method of thermally processing alloy steel, and more particularly to a method of thermally processing alloy steel to produce a microstructure and low hardness level required to increase its response to machining or other processing requiring low hardness without adversely affecting the ability of the steel to respond to final hardening treatment.

Certain alloy steels, generally referred to as ultra high strength steels, are capable, when properly heat treated, of developing extremely high tensile strength, and have particular application for use in the aerospace industry for a wide variety of structural components. In particular, the ultra high strength steels are used for aerospace components requiring maximum strength, such as landing gear, ribs, spars, struts, as well as rocket motor cases, vessels, and the like.

A typical ultra high strength alloy steel is disclosed in U.S. Pat. 2,791,500 and contains additions of nickel, chromium, molybdenum, silicon and manganese. By subjecting an alloy of this type to a hardening heat treatment which consists of normalizing at 1700° F., austenitizing at 1600° F., quenching, and temperating 575° F., a tensile strength in the range of 275,000 to 305,000 p.s.i. and a hardness in the range of 534 to 601 BHN can be obtained. In the fully heat treated condition, this alloy has a microstructure of essentially tempered martensite, and as it has a high hardness, machinability is possible, but only at reduced machining speeds and at some sacrifice in tool life. Therefore, it has been the practice when dealing with ultra-high strength alloys of this type to rough machine and semi-machine the component before the final hardening treatment. In general, the customary procedure for processing components of ultra high strength alloy steel has been to anneal before rough machining. After rough machining, the steel is subjected to a normalizing treatment, followed by an anneal and then semi-finish machined. Following the semi-finish machining, the alloy is then subjected to the final hardening treatment and subsequently final machined.

With this conventional procedure, a heat treatment is interspersed between the rough and semi-finish machining operation. As mentioned above, the intermediate heat treatment consists of normalizing for structural uniformity, and the air hardening characteristics of the alloy then necessitate an anneal to soften the alloy for the subsequent semi-finish machining.

The present invention is directed to a novel heat treatment for ultra-high strength alloy steels which increases the ability of the steel to be machined or otherwise processed without affecting the mechanical properties of the final product. In accordance with the invention, the steel is subjected to a double thermal process. In the first thermal treatment of the process the steel is heated to a temperature above 1200° F. and below the recognized lower critical temperature on heating and held at this temperature for a period of time sufficient to cause numerous small areas of the steel to transform to austenite. On cooling to a temperature below the martensitic finish temperature the austenite is transformed to fresh martensite. Following this initial thermal treatment, the steel is reheated for a second thermal treatment in the range of 1250° F. to 1350° F. and cooled. During the first thermal treatment a large number of spheroidal carbides are produced with a limited amount of fresh martensite uniformly dispersed throughout the microstructure, and the second thermal treatment tends to spheroidize the fresh martensite into carbide particles to provide a uniform spheroidal microstructure, as well as providing a uniform lower hardness value, which increases the machinability of the steel.

Following the double thermal process, the steel can be rough machined and semi-finish machined or otherwise cold processed and after processing the steel can be subjected to the standard thermal treatment to provide the desired mechanical properties.

The heat treating process of the invention eliminates the normalize and anneal normally required between the rough and semi-finish machining operation in a conventional process. By eliminating the normalize and anneal, a substantial overall time and cost savings are achieved.

The heat treatment of the invention provides a uniform microstructure and lower hardness level which increases the machinability index of the steel. This substantially reduces the machining time as well as the overall processing time for the component.

As a further advantage, the uniform lower hardness value is obtained without adversely affecting the ability of the steel to respond to the final thermal treatment so that no loss results in mechanical properties in the final product.

The heat treatment of the invention also provides a more uniform microstructure and hardness from part-to-part. This improvement in uniformity of hardness facilitates machining, or other processing, for the components are normally processed by automatically programmed tools in which the tools are set up to handle the hardest components normally expected to be encountered and components having a lesser hardness are processed at a less than optimum rate. However, by obtaining greater uniformity in hardness by use of the process of the invention, the automatic processing operation can be more accurately controlled, thereby resulting in an overall time and cost savings in the processing operation.

Other objectives and advantages will appear in the course of the following description.

The drawings illustrate the best mode presently contemplated of carrying out the invention.

In the drawings:

FIG. 1 is a flow sheet illustrating the process of the invention;

FIG. 2 is a curve showing the hardness of a typical ultra high strength steel following heat treatment at various temperatures:

FIG. 3 is a curve showing the hardness obtained on the samples of FIG. 2 following a second thermal treatment at 1325° F.;

FIG. 4 is a photomicrograph showing the microstructure of the steel after a thermal treatment at 1350° F.;

FIG. 5 is a photomicrograph showing the microstructure of the steel of FIG. 4 after a second thermal treatment at 1325° F.;

FIG. 6 is a curve showing the hardness of a second ultra high strength steel following heat treatment at various temperatures;

FIG. 7 is a curve showing the hardness obtained on the samples of FIG. 6 following a second thermal treatment at 1250° F.;

FIG. 8 is a curve showing the hardness of a third ultra high strength steel following heat treatment at various temperatures; and

FIG. 9 is a curve showing the hardness developed in the samples of FIG. 8 following a second thermal treatment at 1325° F.

The heat treatment of the invention can be applied to ultra high strength alloy steel, capable of developing an ultimate strength of over 200,000 p.s.i. and a final hardness in excess of 500 BHN by either a quench and temper treatment, or a normalize, quench and temper treatment. Alloys of this type can develop a partial martensitic structure on cooling to below the martensitic finish temperature from a temperature above 1200° F. and below the recognized lower critical temperature on heating. The heat treatment has particular application to alloy steels having the following range of composition in weight percent:

	Percent
Chromium	0.40–1.50
Molybdenum	0.15–1.10
Silicon	0.15–2.00
Manganese	0.40–1.25
Carbon	0.25–0.60
Iron	Balance

The steel may also contain from 0.40 to 3.0% nickel, 0.03 to 0.60% vanadium, and up to about 0.1% of aluminum.

Examples of the specific ultra high strength alloy steels which can be utilized in the process of the invention are as follows:

	1	2	3	4	5	6
Carbon	0.40	0.40	0.46	0.46	0.45	0.30
Manganese	0.65	0.70	0.75	0.75	0.55	0.55
Silicon	0.30	1.60	0.25	0.35	0.27	9.65
Chromium	0.80	0.90	1.05	1.05	0.95	1.25
Molybdenum	0.25	0.45	1.00	2.00	0.55	0.50
Nickel	1.80	1.90	0.55	0.55		
Vanadium		0.07	0.08	0.50	0.30	0.25
Iron	Bal.	Bal.	Bal.	Bal.	Bal.	Bal.

As illustrated in FIG. 1, the steel is normalized followed by a double thermal process. The normalizing consists of heating the steel to a temperature in the range of 1600° F. to 1900° F. and maintaining the steel at the normalizing temperature for a period of time sufficient to obtain complete solution of the carbides. The holding time at temperature is generally a minimum of 30 minutes per one inch of section thickness. The steel is then cooled. The specific rate of cooling is not critical, other than the rate of cooling should be no slower than cooling in ambient air.

As illustrated in FIG. 1, following the normalizing, the steel is subjected to a thermal treatment above 1200° F. and beneath the recognized lower critical temperature on heating (Ac_1), and preferably in the range of 1250° F. to 1375° F. and held at this temperature for a sufficient period of time to cause numerous small areas of the microstructure to transform to austenite and cause the remaining carbides to spheroidize. The time at temperature is generally at least 8 hours and preferably in the range of 8 to 12 hours.

Following the first thermal treatment, the steel is cooled, preferably by air cooling, to a temperature below the martensitic finish temperature(M_f). The specific rate of cooling is not critical. During cooling the austenite is transformed to fresh martensite and a microstructure is produced that exhibits a partially spheroidized structure with small areas of fresh martensite dispersed throughout.

After cooling, the steel is reheated for a second thermal treatment in the range of 1250° F. to 1350° F. and held at temperature for a period of at least 8 hours, and preferably in the range of 8 to 12 hours, and subsequently cooled to room temperature. Again the rate of cooling is not critical, and air cooling is preferred.

During the second thermal treatment, the fresh martensite tends to spheroidize into carbide particles to provide a uniform spheroidal microstructure. Hardness is related to the chemistry of the alloy and to the heat treatment, while machinability is dependent on the hardness and the microstructure. The spheroidal condition developed by the double thermal process provides the optimum microstructure and uniform low hardness level for machining or other cold processing.

As shown in FIG. 1, following the double thermal process, the steel is rough and semi-finish machined, and after machining, it is subjected to the standard thermal treatment to provide the ultimate mechanical properties for the alloy. The standard thermal treatment consists of austenitizing, quenching in the proper media, depending on the section size, and tempering to the desired strength level. After the final hardening treatment, the alloy can then be subjected to the final machining.

While FIG. 1 illustrates the process of the invention as applied to a machining operation, it is contemplated that the steel, after the double thermal process can be subjected to any type of processing or cold working and the uniform low hardness level will provide optimum conditions for such processing.

FIGS. 2 and 3 are curves, illustrating specific hardness values developed during the first and second thermal treatments on alloy steel samples having the following composition in weight percent:

	Percent
Nickel	1.85
Chromium	0.85
Molybdenum	0.40
Silicon	1.60
Manganese	0.75
Vanadium	0.08
Carbon	0.40
Iron	Balance

The samples were normalized at 1650° F. for 1 hour and air cooled. A first group of samples was thermally treated at 1275° F. for a period of 10 hours and air cooled. Additional groups of samples were subjected to similar thermal treatments at 1300° F., 1325° F., 1350° F., and 1375° F., respectively.

FIG. 2 illustrates the hardness of the samples following the first thermal treatment. From FIG. 2 it can be seen that the steel thermally treated at 1325° F. (sample C) had the lowest hardness of approximately 255 BHN, while the steel thermally treated at 1275° F. and 1300° F. (Samples A and B) had somewhat higher hardness values of 272 BHN and 260 BHN, respectively. The steel ther-

mally treated at 1350° F. and 1375° F. (samples D and E) had higher hardness values, above 290 BHN.

Following the first thermal treatment, all of the samples A–E were thermally treated at 1325° F. for 10 hours and air cooled. FIG. 3 illustrated the hardness of the steel samples A–E following the second thermal treatment. The curve in FIG. 3 indicates that the hardness values have leveled out considerably from the values shown in FIG. 2 and this flattening out of the hardness curve by a second thermal treatment is unexpected. For example, Samples A, B and C all showed a hardness of approximately 230 BHN following the second thermal treatment at 1325° F., while the hardness of sample D was approximately 250 BHN, and that of sample E was approximately 255 BHN. This flattening out of the hardness curve is novel and unforeseen. One would normally expect that a second thermal treatment would reduce the hardness to some extent, but one would further expect that the basic hardness pattern, as shown in the curve of FIG. 2, would be retained. However, this is not the case, for the second thermal treatment alters the hardness pattern, as shown in FIG. 3, and this provides distinct and important advantages. As an example, the first thermal treatment at 1325° F. produces a satisfactory hardness of 255 BHN for machining, but from a commercial standpoint ia would be difficult to accurately maintain this precise temperature, particularly when dealing with components of irregular shape. If the temperature was not precisely controlled at 1325° F., the hardness could vary considerably because of the shape of the curve as shown in FIG. 2 and also because of chemical variations from heat to heat. However, the second thermal treatment, by levelling out the hardness curve, insures that the hardness throughout the part, as well as from part-to-part will be substantially uniform regardless of any variations of hardness that may exist after the first thermal treatment.

The photomicrograph, FIG. 4, illustrates the microstructure of the steel of the composition set forth above after normalizing at 1650° F. for one hour, air cooling, thermally treating at 1350° F. for 10 hours and air cooling. In FIG. 4, the gray patches represent new or fresh martensite formed following the 1350° F. thermal treatment which results in variable hardness and is detrimental to machinability. FIG. 5 is a second photomicrograph of the same steel after the second thermal treatment of the process at 1325° F. for 10 hours and air cooling. FIG. 5 shows the increased proportion of spheroidized particles with absence of gray patches, indicating the spheroidizing of the new martensite into the spheroidal microstructure which reduces the hardness level and increases the machinability of the steel.

FIGS. 6 and 7 are hardness curves, similar to the curves shown in FIGS. 2 and 3, developed during the first and second thermal treatments on an ultra high strength alloy having the following composition in weight percent:

Carbon	0.40
Manganese	0.65
Silicon	0.30
Chromium	0.80
Nickel	1.80
Molybdenum	0.25
Iron	Balance

The samples of this steel were normalized at 1650° F. for 1 hour and air cooled. A first group of samples was thermally treated at 1275° F. for 10 hours and air cooled, while additional groups of samples were subjected to similar thermal treatments at 1300° F., 1325° F., 1350° F. and 1375° F., respectively.

The curve in FIG. 6 shows the hardness of the steel samples following the first thermal treatment, and illustrates the abrupt variation in hardness between the samples, with the sample heated at 1275° F. having a hardness of approximately 252 BHN and the sample treated at 1375° F. having a hardness of about 555 BHN.

Following the first thermal treatment all of the samples were subjected to a second thermal treatment at 1250° F. for 10 hours and air cooled. The curve in FIG. 7 shows that the hardness values of all samples leveled out after the second thermal treatment and are all in the range of 240 to 260 BHN.

FIGS. 8 and 9 are hardness curves, similar to the curves shown in FIGS. 2 and 3, developed during the first and second thermal treatments on an ultra high strength alloy having the following composition in weight percent:

Carbon	0.45
Manganese	0.75
Silicon	0.25
Chromium	1.05
Nickel	0.55
Molybdenum	1.00
Vanadium	0.08
Iron	Balance

The samples of this steel were normalized at 1650° F. for 1 hour and air cooled. A first group of samples was thermally treated at 1275° F. for 10 hours and air cooled, while additional groups of samples were subjected to similar thermal treatments at 1300° F., 1325° F., and 1375° F., respectively.

The curve in FIG. 8 shows the hardness of the steel samples following the first thermal treatment and illustrates the substantial difference in hardness between the samples.

Following the first thermal treatment all of the samples were subjected to a second thermal treatment at 1325° F. for 10 hours and air cooled. As in the case of the other steels, the curve in FIG. 9 illustrates that the hardness values had leveled out after the second thermal treatment.

The double thermal process provides a uniform lower hardness level for the steel, so that machining as well as other processing can be accomplished within a substantially shorter period of time. Important too, is the fact that the improved machinability is obtained without adversely affecting the ability of the steel to respond to the final hardening treatment, so that the mechanical properties of the final hardened steel are comparable to those of a steel processed in accordance with conventional procedures.

A further important advantage of the invention is that greater uniformity in microstructure and hardness are obtained from within the part and from part-to-part by virtue of the double thermal process. This result is unexpected and the second thermal treatment insures a substantially uniform hardness regardless of hardness variations after the first thermal treatment. As the hardness of the alloy is more uniform from part-to-part, the automatically programmed machining or other cold processing operations can be keyed to a lower hardness which thereby reduces the processing time.

The heat treatment of the invention can be applied to articles of both large and small mass, as well as flat or irregularly contoured articles.

While the above description has illustrated the double thermal process following normalizing, it is contemplated that, in some situations, depending on the specific alloy involved and the ultimate properties desired, the alloy can be subjected to the double thermal process and machined, or otherwise processed, prior to normalizing.

Various modes of carrying out the invention are contemplated as being within the scope of the following claims particularly pointing out and distinctly claiming the subject matter which is regarded as the invention.

I claim:

1. A method of heat treating an ultra high strength alloy steel to increase the response of the steel to cold processing without adversely affecting the ability of the steel to respond to final hardening treatment, comprising the steps of subjecting an ultra high strength alloy steel capable of developing an ultimate strength of more than

200,000 p.s.i. and having the following composition in weight percent:

	Percent
Chromium	0.40 to 1.50
Molybdenum	0.15 to 1.10
Silicon	0.15 to 2.00
Manganese	0.40 to 1.25
Carbon	0.25 to 0.60
Iron	Balance

to a first thermal treatment by heating said steel to a first temperature above 1200° F. and below the recognized lower critical temperature on heating and holding the steel at said first temperature for a period of time to cause numerous areas of the steel to transform to austenite, cooling the steel from said temperature to a temperature below the martensitic finish temperature to transform the austenite to fresh martensite and develop a microstructure exhibiting spheroidized carbides and patches of fresh martensite, subjecting said steel to a second thermal treatment by reheating the steel to a second temperature in the range of 1250° F. to 1350° F. to spheroidize the fresh martensite into a spheroidal structure, and cooling the steel, said second thermal treatment providing a uniform lower level of hardness and uniform microstructure to facilitate cold processing of the steel prior to final hardening.

2. The method of claim 1, wherein the steel also contains from 0.40% to 3.0% of nickel.

3. The method of claim 1, wherein the steel also contains from 0.03 to 0.60% of vanadium.

4. The method of claim 1, wherein the first temperature is in the range of 1250° F. to 1375° F.

5. The method of claim 1, wherein the steel is held at both the first and second temperatures for a period of at least 8 hours.

6. The method of claim 1, and including the steps of cold processing the steel after the second thermal treatment, and thereafter heat treating the processed steel to provide an ultimate strength above 200,000 p.s.i.

7. The method of claim 6, wherein said cold processing is machining.

8. A method of heat treating an ultra high strength alloy steel to increase the machinability of the steel without adversely affecting the ability of the steel to respond to subsequent hardening treatment, comprising the steps of normalizing an ultra high strength alloy steel capable of developing an ultimate strength above 200,000 p.s.i. and having the following composition in weight percent:

	Percent
Chromium	0.40 to 1.50
Molybdenum	0.15 to 1.10
Silicon	0.15 to 2.00
Manganese	0.40 to 1.25

	Percent
Carbon	0.25 to 0.60
Iron	Balance

heating the normalized steel to a first temperature above 1200° F. and below the recognized lower critical temperature on heating, maintaining the steel at said first temperature for a period of at least 8 hours to cause numerous areas of the steel to transform to austenite, cooling the steel to below the martensitic finish temperature to transform the austenite to fresh martensite and develop a microsructure exhibiting spheroidized carbides and patches of fresh martensite, heating the steel to a second temperature in the range of 1250° F. to 1350° F., maintaining the steel at said second temperature for a period of at least 8 hours to spheroidize the fresh martensite, and cooling the steel, said treated steel having a uniform lower level of hardness and uniform microstructure to facilitate cold processing of the steel prior to final hardening.

9. The method of claim 8, wherein the steel also contains from 0.40% to 3.0% nickel.

10. The method of claim 8, wherein the steel also contains from 0.03% to 0.60% vanadium.

11. The method of claim 8, and including the steps of cold processing the steel, and thereafter hardening the processed steel by heat treatment to provide an ultimate strength above 200,000 p.s.i.

12. The method of claim 11, wherein said cold processing comprises a preliminary machining operation.

13. The method of claim 11, wherein the hardening comprises the steps of austenitizing the steel, quenching the steel, and tempering.

14. An alloy steel produced by the method of claim 1 and characterized by having good machinability, structural uniformity and a hardness less than 255 BHN.

15. The steel of claim 14, and containing at least one metal selected from the group consisting of 0.40% to 3.0% nickel, 0.03% to 0.60% vanadium, and up to 0.1% of aluminum.

16. The method of claim 1, wherein the steel also contains from 0.03% to 0.60% vanadium and from 0.40% to 3.0% nickel.

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RICHARD O. DEAN, Primary Examiner

U.S. Cl. X.R.

148—36, 134, 143, 144

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,732,127 Dated May 8, 1973.

Inventor(s) ROLAND W. FURGASON

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

In Sheet 1 of the Drawings, Cancel "Fig.4" and substitute therefor ---Fig. 5---, Cancel "Fig. 5" and substitute therefor ---Fig. 4---.

Signed and sealed this 10th day of September 1974.

(SEAL)
Attest:

McCOY M. GIBSON, JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents

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