GENERAL DYNAMICS
Fort Worth Division
Code Ident: 81755

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DATED: 22 March 1982
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HEAT TREATMENT, FORGING AND PROCESS **REQUIREMENTS,** TYPE **D6ac** STEEL

Approved & Released
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&
Data Group
By CWA *Date* 5 Aug 85

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Dated: 21 June 1985

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Dated: 21 June 1985

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CHANGE INDEX - REVISION G

Item	**Paragraph** No.	Reason for Change
1	3.4.2.2	To incorporate amendment 1 and help clarify.
2	3.4.5	To incorporate amendment 2.
3	3.4.7.1	To help clarify.
4	3.4*7.3	To help clarify.

HEAT TREATMENT, FORGING AND PROCESS REQUIREMENTS, TYPE D6ac STEEL

1.0 SCOPE

1.1 This specification establishes requirements for the heat treatment and processing of parts made from material procured to the requirements of Fort Worth Division Material specification FMS-10 11.

1.2 Parts manufactured to the requirements of this specification are intended for design applications requiring tensile strengths of 180,000 **PSI** (180 KSI) or higher.

2.0 APPLICABLE DOCUMENTS

2.1 The following 'documents form a part of this **specif ication** to the extent specified herein. Unless otherwise specified, the document issue in effect on date of purchase order shall be applicable. The effectivity of specifications or documents cited within these documents shall be in accordance with the documents listed below.

ASTM E-384	Standard Method of Test for **Microhardness** of Materials
Federal Test Method Standard No. 151	Metals, Test Methods
MIL-C-14550	Copper Plating, **Electrodeposited**
MIL-I-6868B	Inspection Process, Magnet **ic** Particle
MIL-H-6875	Heat Treat ment of Steels (Aircraft Pratt ice), Process for
FMS-1011	Procurement Specification for Steel, **Cr-Mo-V-Ni,** Type D6ac
FPS-0040	Zoning Standards for Magnetic Particle Inspection, Process Specification for
FPS-1032	Shot Peening Metal Parts
FPS-1033	Welding, Fusion, General **Specification** for
FPS-1041	Engineering, Processing and Inspection Requirements for Structural Forgings
FPS-1095	Fusion Welding Process, General Specification for
FPS-107O	**Nital** Etching of Steel Parts
FPS-1098	Drilling and Reaming of Alloy Steel Parts Heat Treated to 180,000 psi and above

FPS-3028	Control of Thermal Processing Equipment
NDTS 1500	Hardness and Conduct ivity Testing
NDTS 2101	Magnetic Particle Inspection
NDTS 9111	Nital Etch Inspection

3.0 REQUIREMENTS

3.1 General: Heat treat ment, forging and processing procedure and equipment shall be in accordance with the requirements of MIL-H-6875, Fort Worth Division Process Specification FPS-1041 and this specif ication. If the requirements of these documents conflict with this specification, this specification shall apply.

3.1.1 Qualification Procedures: The equipment and methods used by a heat treat or forging source shall be approved by Fort Worth Division Quality Assurance. The source shall not submit production parts to Fort Worth Division prior to this approval nor prior to reapproval in case of disqualification.

3.1.1.1 Heat Treat Source: Approval of a heat treat source shall be based on the results of tests conducted to evaluate the suitability of all equipment and processes used. Tests shall include, but not be restricted to, determination of mechanical properties, changes in surf ace them ist ry, and microstructure of parts and test specimens.

3.1.1.2 Qualification Continuance: The equipment and methods used by a heat treat or forging source will remain qualified for performance under this specification only so long as parts and test specimens continue to meet the criteria and requirements of this specif icat ion. Rejection of parts, test specimens or test data may be cause for disqualification of the source.

3.1.2 Thermal Processing shall be accomplished on the entire piece of material simultaneously, not to local areas, unless otherwise specified by Fort Worth Division Engineering.

3.2 "Equipment Control

3.2.1 All heat treating furnaces, salt baths, and other equipment shall be maintained in opt i mu m operating condition; it is absolutely essential that the probability y of reheat treat ment be minimized. The use of inert atmospheres for heat treating is recommended.

3.2.2 The design, construction and maintenance of the heating equipment shall be such that the temperature in any part of the working zone will not vary more than $\pm 25^{\circ}F$ from the control set point for annealing, normalizing or hardening operations or $\pm 10^{\circ}F$ from the control set point for tempering operations.

3.2.3 All heating equipment shall be provided with suitable automatic temperature control and recording devices. The accuracy of the temperature recording instruments shall be within $\pm 1\%$ of the temperature indications received from the calibrating instruments. Furnace control surveys and instrument checks shall be made in accordance with MIL-H-6875 or FPS-3028.

3.2.4 Means shall be provided for adequate agitation of quenching media. Prior to the quenching operation, quench media temperature shall not exceed 4000F. The temperature rise of the media during the quenching operation shall be limited to 25°F; heating and refrigeration shall be provided as necessary.

3.2.5 Salt Baths for Normalizing or Hardening: The salt used in the salt baths shall be of a type and grade which will not react objectionably with the steel being heat treated. The baths shall be checked daily, when in use, to insure that the salt produces no detrimental effect on the steel being heat treated. A test specimen as described in paragraph 4.3 shall be prepared. The specimen shall be immersed in the salt bath for the same period of time as required for the parts it represents and then oil quenched. The as-quenched test specimen shall be suitably tempered to the strength level required for the parts, sect ioned and evaluated by testing for conformance to the requirements of Paragraph 4.3. If these requirements are not met, the salt bath must be rectified prior to further use.

3.2.6 Furnace Atmosphere: Furnaces shall be provided with equipment sufficient to maintain the furnace atmosphere so that during heat treatment the surface chemistry changes do not exceed the limits specified in Paragraph 3.4.2. Carbon potential may be determined by any method approved by Fort Worth Division Quality Assurance.

3.3 Forging Procedure (when applicable)

3.3.1 General: Unless otherwise specified, forgings shall be manufactured in accordance with Fort Worth Division Process Specif icat ion FPS- 1041.

3.3.2 Preheating: Preheat material to 1400°F. Soak at 1400°F until material ' temperature has equalized with furnace temperature. Raise temperature from pre-heat temperature to 2250°F maximum. Soak at temperature approximately one hour per inch of maximum section thickness.

3.3.3 Forging: Forging shall be accomplished between 1800°F and 2250°F. Material shall not be heated above 2250°F. When multiple forging operations are necessary, the material must be soaked at 2250°F maximum for the period of time specified in Paragraph 3.3.2 prior to each reforging operation.

3.3.4 Post-Forging Treat ment: Material must be normalized (or normalized and tempered) with a maximum hardness of 327 Brinell or equivalent after forging.

3.4 Heat Treat Procedures

3.4.1 Cleaning Requirements: Prior to any heat treating operations, material shall be substantially clean and free from grease, oil, foreign metallic particles, scale, or other detrimental contaminants. Clean by one or more of the following methods when necessary vapor decreasing, alkaline cleaning and rinsing, or abrasive blasting.

3.4.2 Surface Chemistry Requirements:

3.4.2.1 Surface chemistry change examination specimens shall be processed with each heat treat load during operations at temperatures above 1200°F on parts from which less than .020 inch of material is to be removed after heat treatment. The specimens shall be exam ined per Paragraph 4.3 and shall meet the f ollo wing requirements:

(1) Carburization or carbon restoration shall not be permitted.

(2) Nitrides shall not be permitted.

(3) Total decarburization shall not be permitted.

(4) Partial decarburization (carbon depletion) shall not exceed the limits established in Section 4.3

(G) 3.4.2.2 The requirements of Sections 3.2.5, 3.2.6, 4.0 and 7.0 apply regardless of the surface chemistry control methods used. In addition, copper plating is required for all parts heat treated in endothermic atmospheres unless otherwise approved by Fort Worth Division Quality Control. Copper plating is not required on parts or areas of parts from which at least .020 inch of material is removed from each surface after heat treatment. Atmosphere control specimens and tensile specimens shall not be copper plated. When copper plating is used, it shall be accomplished as' follows:

(1) Copper plate per MIL-C-14550, Class 1, with the exception tha the copper thickness shall be .0005 inches thick minimum to .001 inches thick maximum.

NOTE: The thickness of plating applies to surfaces which can be touched by a ball 0.75 inches in diameter. If this cannot be met, the thickness should be sufficient for plating continuity and uniform appearance.

(2) Heat treat as applicable, including quench and final te roper. '

'(3) Strip copper plating using alkaline-sodium cyanide type strippers, such as Enthone, Inc., Enstrip "a", Enstrip "s", Enstrip "SGO", or their direct equivalent. Acid and/or electrolytic stripping methods are strictly prohibited.

(4) Bake at 375°F ± 25°F for 24 hours ± 1 hour to remove entrapped hydrogen.

3.4.3 Heat Treating Temperature: The furnace or salt bath temperature at the beginning of a heat treat operation shall be as specified for the particular operation except that prior to annealing, normalizing, or hardening (in cases where warpage or cracking might result from too rapid heat ing), it is permissible to preheat to 1200°F maximum for a period of time sufficient to permit temperature equalization of the work; or as specified in 3.4.7.4.1 (3)(c).

NOTE: All time-temperature specifications are soak times at temperature.

3.4.4 Annealing: Heat part to 1550°F ± 25°F and soak not less than one hour or 1/2 hour per inch of maximum section thickness, whichever is greater. Furnace cool at a rate not to exceed 50°F per hour to 1000°F and air cool.

(G) 3.4.5 Normalizing: Heat part to 1725° ±25°F and soak for not less than one hour or 1/2 hour per inch of maximum section thickness, whichever is greater. Cool in still air to below 150°F. Temper at 1175°F to 1250°F for a minimum of 2 hours or 2 hours per inch of maximum section thickness, whichever is greater.

3.4.6 Stress Relieving (Prior to Heat Treatment) - Detail parts going into weldments which are out-of-flat and weld details that have been cold or locally hot straightened in any manner, shall be stress relieved straightened to the Total Indicator Reading (T. I. R.)

flatness requirements of the engineering drawing. Stress relieving of non-weld detail parts after cold or locally hot straightening is recoin mended but is not mandatory. Stress relieving shall be accomplished by heating part to 1175*F ± 25*F and holding for one hour or one hour per inch of thickness whichever is greater. Cool in still air. (Refer to FPS-1033 or FPS-1095 for temperatures and times for complete weld assemblies). Alternate procedures are permissible if approved by Fort Worth Division Quality Assurance and Engineering.

NOTE: The purpose of stress relieving is to remove the residual stresses in parts resulting from forging, machining, forming, straightening, heat processing, welding, etc., to mini mize the effect on subsequent operations, such as subsequent welding and/or heat treat ment. Finished machined parts that meet the flatness requirements of the Engineering Drawing, unrestrained, do not require stress relief. [t is recoin mended that large parts be rough machined, stress relieved and subsequently finished machined.

3.4.7 Hardening and Tempering

(G) 3.4.7.1 All materials must be in the normalized and **tempered** condition prior to hardening and tempering except sheet may be in the **annealed** condition. All details going into weldments must be in the applicable condition noted in 3.4.6 prior to welding, hardening, or tempering. W eldments may be hardened and tempered without further normalizing.

NOTE: (1) Material normalized and tempered per Fort Worth Division Specification FM$1011 is acceptable for hardening and tempering without additional processing.

(2) When hardening annealed sheet material, temperatures on the high side of the range and the maximum time at temperatures are recommended.

3.4.7.2 When tensile coupons are required in accordance with Paragraph 4.1, they shall accompany parts through all heat treating processes and not be thermally processed separately unless requested or approved by Fort Worth Division Quality Assurance.

(G) 3.4.7.3 Conventional Hardening and Tempering

(1) **Austenitizing:** Heat part to **1700°F ±** 25*F and soak at temperature not less than 1/2 hour or 1/2 hour per inch of maximum section thickness, whichever is greater. Preheating to **1200°F** maximum is permissible.

(2) Quench into agitated oil or agitated salt followed by air cooling to below **150°F.** For parts thicker than a two-inch equivalent round, quench into agitated oil at **140°F ± 10°F.** Consult **MIL-H-6875** to determine equivalent round sizes. For thinner parts either an agitated oil or agitated molten salt quench may be used.

(A) The salt shall be molten at a maximum of 400°F. After air cooling to below **150°F,** rinse in hot water until all traces of the quench salt are removed.

(B) The oil quenching temperature shall be **130°F** to **200°F.**

The "as-quenched" or "as quenched and stress relieved" hardness of representative parts shall meet the requirements of Paragraph 3.4.7.4.1(4).

(3) Tempering If a delay sufficient to initiate cracking is anticipated before the first tempering operation, stress relieve for a minimum of 2 hours at a temperature of 375°F to 450°F. The tempering operations shall be performed in accordance with Table I for the strength level specified on the engineering drawing. Each tempering operation shall be for a minimum of two (2) hours or one (1) hour per inch of maximum section thickness, whichever is greater, followed by air cooling to room temperature. Final machining and/or grinding operations shold be performed between tempering operations when possible.

NOTE: Unless otherwise specified by Fort Worth Division Quality Assurance Department, the vendor may use the following alternate tempering procedures, at his own option:

(1) First temper shall be at 550°F minimum for two (2) hours or one (1) hour per inch of thickness whichever is greater.

(2) Second temper shall be as specified in Table 1 for the required strength level and shall not be less than two (2) hours or one (1) hour per inch of thickness, whichever is greater.

3.4.7.4 Aus-Bay Quenching to Minimize Heat Treat Distortion: The following processes (Paragraphs 3.4.7.4.1 and 3.4.7.4.2) produce acceptable mechanical properties and are recommended for use when distortion must be held to a minimum.

3.4.7.4.1 Using Conventional Heat Treat Equipment: Aus-Bay quenching may be performed in the following manner using multiple furnaces:

(1) Preheat: Preheat per Paragraph 3.4.3.

(2) Austenitizing: Austenitize per Paragraph 3.4.7.3(1) except step cooling from 1700°F to 1550°F after the required time at 1700°F and equalization of part temperature prior to quenching is permissible.

(3) Quench to Aus-Bay: Transfer work to a separate furnace and hold for a maximum of 2 hours to permit part temperature equalization at 975°F ± 25°F. Parts from which less than .020 inch is to be removed after heat treatment shall be maintained under sufficient protective environment during the hardening and transfer to the Aus-Bay furnace to meet the requirements of Paragraph 3.4.2.

(a) There shall be a minimum of two recording thermocouples run with each furnace load of production parts that are Aus-Bay quenched. The thermocouples shall be inserted in steel thermocouple blocks representative of the thickest and thinnest sections of the parts being heat treated. The recording thermocouples shall record cent inuously the entire cycle from the time the parts are loaded into the austenitizing furnace until the parts are liquid quenched. The thermocouples may be disconnected prior to quenching into molten salt at 975°F or the final quench media. If the parts are furnace or air cooled from the austenit izing temperature to 975°F the thermocouples shall record cent inuously to provide objective evidence that the cooling rate from 1350° to 1150° is not less than 6°F per minute. Furnace temperature charts shall be maintained as required in Section 6.

NOTE: Copper plating significantly decreases the heat absorption rate of steel. Therefore, thermocouple blocks used during heat treating of parts copper plated per paragraph 3.4.2.2 shall also be copper plated.

(b) Air cooling after removal from the austenitizing furnace for a short period of time, to reduce overheating of the 975°F furnace and to hasten the cooling of thick sections, is permitted providing the temperature of the part does not fall below 950°F and the requirements of Paragraph 3.4.2 are met.

(c) Transferring toafurnace setabove or below the Aus-Bay temperature range of 975°F ± 25°F to allow for excessive heat loss or overheating is permitted. After the load has been transferred to the Aus-Bay furnace, the furnace temperature shall be set at 975°F. The temperature of the part at any place shall not fall below 950°F.

(d) The rate of cooling of the part(s) from 1350°F to 1150°F must not be less than 6°F per minute.

(e) The size of the heat treat load and the manipulation of the furnaces shall be such that the time required to equalize at 975°F ± 25°F does not exceed 2 hours.

(4) Quench from Aus-Bay: Quench from the Aus-Bay furnace per Paragraph 3.4.7.3(2). Hardness of the maximum and minimum section thickness of representative parts Aus-Bay Quenched shall be obtained after quenching or after stress relieving up to 450°F. The parts shall meet the following hardness requirements, as applicable.

"As-Quenched" Hardness	Hardness After Stress Relieving Up to 450°F
Rc 55 minimum	RC 53 minimum

(5) Tempering: Temper per Paragraph 3.4.7.3(3).

3.4.7.4.2 Using Specialized Heat Treat Equipment: The Aus-Bay Quench Process may be performed using a single fast heating and cooling furnace (such as Luminous wall furnaces) if conducted as follows:

(1) Preheat: Step heat parts and furnace slowly, to prevent warpage or cracking, to 1700°F ± 25°F. Heating steps should not exceed 500°F increments.

(2) Austenitizing: Austenitize per Paragraph 3.4.7.3(l).

(3) Quench to Aus-Bay: continuoulsy cool the part(s) in the furnace to 975°F ± 25°F. The rate of cooling of the part(s) from 1350°F to 1150°F must not be less than 6°F per minute. Hold part(s) at 975°F + 25°F to permit part temperature equalization at that temperature.

(4) Quench from Aus-Bay: Quench from 975°F per Paragraph 3.4.7.3(2).

(5) Tempering: Temper per Paragraph 3.4.7.3(3).

3.4.7.5 Aus-Bay Quench Process Verif icat ion Test: A process verif icat ion test specimen shall be processed prior to initial heat treat loads Aus-Bay quenched and under maximum production heat treat load weight and cross section size conditions. The test specimen and test procedures shall conform to Figure 1 and Paragraph 4.4. When changes in maximum furnace loads or section sizes are made, this test must be repeated and shall be repeated as often as deemed necessary by Fort Worth Division Quality Assurance Department. All test conditions and data results are to be reported as per Paragraph 6.0.

3.4.8 Post Heat Treat Cleaning: Cleaning after heat treatment shall be restricted to wet or dry abrasive blasting, vapor decreasing, or alkaline cleaning.

3.4.9 Magnetic Particle Inspection: Rough machined parts may be magnetic particle inspected per MIL-I-6868. Finished machined parts shall be inspected per FPS-0040, or NDTS 2101, Zone O, unless otherwise specified on the engineering drawing. The FPS-0040 or NDTS 2101 Quality Zone specified on the machined part drawings apply at all processing levels.

3.4.10 Straightening of Warped Parts: Parts warped as a result of quenching shall be straight ened in fixtures during the tempering operations. Additional straightening is permitted as follows:

3.4.10.1 Cold straightening after final heat treatment is prohibited, unless otherwise approved by Fort Worth Division Engineering.

3.4.10.2 When required, straightening after final tempering shall be accomplished at 4750F -975°F for parts heat treated to the 240,000 psi level or lower and shall be followed by a stress relief at 950°F ± 25°F for one (1) hour if temperature of part during straightening is or goes below 925°F. For parts heat treated to the 260,000-280,000 psi level, straighten at 500°F ± 25°F and hold at 500°F ± 25°F for one (1) hour after straight ening.

3.4.10.3 Subsequent hardness test ing and magnetic particle inspection are required when the part(s) are straight ened.

3.4.11 Ground Surfaces: When grinding is accomplished prior to the final tempering operation, subsequent stress releiving is not required.

3.4.11.1 When parts are ground after the final tempering operation, stress relieve for one hour at 950°F ± 25°F for parts heat treated to the 240,000 psi level or lower. For parts heat treated to the 260,000-280,000 psi level, stress relieve for three (3) hours at 500°F ± 25°F.

3.4.11.2 Hardness test and magnetic particle inspect all parts in accordance with drawing requirements after stress relieving.

3.4.11.3 In addition to the above requirements, parts which are ground after final heat treatment shall be inspected by nital etching per FPS-107O or NDTS 9111 when specified by the engineering drawing.

NOTE: Grinding involves metal removal operations using grinding stones or alumina vitrified bonded grinding wheels and does not include honing, polishing, or sanding operations.

3.4.12 Drilling and Machining

3.4.12.1 Drilling and machining operations after final heat treatment should be held to a minimum to avoid metallurgical damage to the material. Every precaution must be taken to assure properly machined surfaces with no metallurgical damage to the material. Drilling and reaming shall be performed in accordance with FPS-1098.

3.4.12.2 When drilling or machining is required after final heat to above 220 ksi, parts with evidence of overheating due to such operations shall be rejected. Within one hour after drilling or machining on a fully heat treated part, unless otherwise approved by Fort Worth Division Engineering, stress relieving shall be initiated. Stress relieve for one hour at 500F ± 25°F below the final tempering temperature of the part, except that parts with shot peened surfaces shall be stress relieved at 400F ± 10°F for one hour. If shot peened surfaces are subsequently machined or ground, the parts should be stress relieved and re-shot peened by a Fort Worth Division approved process unless Fort Worth Division Engineering determines that such operations are not necessary.

3.4.13 Shot Peening: Shot peening, when required on the engineering drawing, shall be in accordance with Fort Worth Operation specification FPS- 1032. Shot peening will be done after completion of all fabricating operations such as machining, grinding, heat treating and straightening and prior to the application of finishes such as platings, paints, etc; areas shot peened shall be as indicated on the engineering drawing. All parts with tensile strengths of 220 ksi or greater shall be shot peened. If there is a discrepancy with the engineering drawing, contact Liaison or Metallic Materials and Processes Engineering.

3.4.14 Corrosion Resistant Coatings: Finished machined parts shall be suitably protected in cases where processing delay time is such that surface corrosion might occur. A suitable corrosion protective compound or a paper impregnated with a vapor phase inhibitor may be used.

3.4.15 Surface Finishes: Surface finishes, plating, paints, etc., shall be in accordance with the drawing require ments.

4.0 INSPECTION, TEST AND SAMPLING PROCEDURES, AND QUALITY ASSURANCE PROVISIONS

4.1 Tensile Tests:

4.1.1 Sampling:

4.1.1.1 Testing Specified by Engineering Drawing: When the engineering drawing requires that tensile tests be performed for each part heat treated or each heat treat lot, whichever is specified, material for such tests shall be the same as that used for the part unless otherwise permit ted. identity of the test specimens with respect to the part or heat treat load, as applicable, shall be maintained through all phases of manufacture and reported as per Section 6.0.

4.1.1.2 Additional Tensile Test in% Additional testing beyond the requirements on the engineering drawing, or where the drawing does not specify tensile testing, may be required by Fort Worth Operation Quality Assurance at a frequency to be determined by that depart ment. Unless otherwise specified, the material used for such tests need only be of the same nominal composition as the parts being heat treated.

4.1.2 Tensile Specimens: Tensile test specimens shall conform to Specimen Type Rl, R2, R3, R4, R5, or F2 of Method 211.1 of Federal Test Method Standard No. 151, and shall be of the largest size permitted by the material.

4.1.3 Test Method: Tensile tests shall be conducted in accordance with the requirements of Method 211.1, Federal Test Method Standard 151.

4.1.4 Tensile Specimen Mechanical Properties Requirements: Aft er hardening and tempering, mechanical properties of tensile specimens required per Paragraph 4.1.1.1 and Paragraph 4.1.1.2, as applicable, shall conform to the requirements of Table L The heat treat source shall be responsible for establishing compliance with the required properties and reporting the test results as required by Section 6.2.

4.2 Hardness Tests: Each part shall be hardness tested per NDTS 1500. Hardness values shall meet the require ments of Table L All hardness test results shall be reported for parts and test specimens. Test results, and parts or lots are to be serial numbered or otherwise identified in reference to Section 6.0 and in reference to the parts they represent.

4.3 Surface Chemistry Change Examination: A minimum of one (1) atmosphere control specimen shall be austenit ized with each heat treat load. Prior to heat treatment, the specimen reference surf aces shall be clean and free from all surface decarburizat ion and contamination. Specimen configuration is optional, unless otherwise specified by Fort Worth Division Quality Assurance Depart ment. An as-heat treated section from a broken tensile specimen per Paragraph 4.1 may be used when available if the tensile specimen was finished machined prior to heat treatment. Additional processing shall be as follows:

(1) The atmosphere cent rol specimen shall be tempered to the same heat treat level as the parts. Specimen(s) shall not be cleaned in any manner that will prevent accurate determinant ion of surface chemistry changes which occur during processing.

(2). The specimen shall be prepared for microhardness testing and metallographic examination using proper mounting and polishing procedures to insure flat edge retention.

(3) Microhardness testing to evaluate surface chemistry variations shall be accomplished in accordance with ASTM E-384. A 500 gram load shall be used for microhardness testing. The specimen shall meet the equivalent Rockwell C hardness values specified in the following table based on the conversion from Knoop Hardness Number to R_c value shown in Figure 2.

	HEAT TREAT RANGE			
Distance from edge, inches	180-200 KSI	200-220 KSI	220-240 KSI	260-280 KSI
.002	R_c 36-(*)	R_c 39-(*)	R_c 42-(*)	R_c 46-(*)
.003	38-(*)	41-(*)	44-(*)	48-(*)
.004	40-(*)	43-(*)	46-(*)	50.5-(*)
.006	40-(*)	43-(*)	46-(*)	50.5-(*)
.008	40-(*)	43-(*)	46-(*)	50.5-(*)
.010	40-(*)	43-(*)	46-(*)	50.5-(*)
Core	40-43	43-46	46-49	50.5-53

(*) The maximum hardness shall not exceed the actual core hardness of the specimen by more than one point R_c.

(4) The criteria in (3) above have been established to determine surface chemistry changes caused by improper furnace atmosphere control. Specimens which fail to meet the requirements shall be retested, reviewed and may be accepted by a Fort Worth Division Metallurgist providing the failure is not caused by improper atmosphere control. If the failure was caused by surface chemistry changes, all parts represented by the test

specimens shall be rejected. If the m icrohardness shows an "under-tempered" condition, not detectable by surface hardness testing, the parts represented by the specimens may be retempered.

(5) The test specimen shall be examined metallographically at lOOX to 250X magnification for total decarburization. The entire heat treat load represented by the specimen tested shall be rejected if the test specimen shows complete depletion of carbon at any depth.

(6) All microhardness test data shall be reported. The mounted specimens which were tested shall be suitably identified and maintained at the supplier's facility. They shall be made available if requested by the Fort Worth Division.

(7) In case of question, a specimen may be removed from a part from an area designated by Engineering as "non-critical" and used for the test required in this paragraph. The specimen shall be reviewed by a Fort Worth Division Metallurgist. Data from this specimen takes precedence over data obtained from the atmosphere control specimen or a broken tensile specimen.

4.4 Aus-Bay Quench Process Verification Tests:

4.4.1 A finished machined D6ac test bar of dimension shown in Figure 1 and of a diameter equal to or greater than the maximum equivalent round of the production part(s) being processed shall be processed with the heat treat load being Aus-Bay Quenched per Paragraph 3.4.7.5. The steel used for this test specimen need not be the same heat or lot as that of the steel from which the part(s) being heat treated are made, but shall be of the same nominal chemical composition.

4.4.2 After quenching per Paragraph 3.4.7.4.1(4), cut the specimen at a distance from one end 1.5 times the diameter, exercising care and adequate cooling. Grind the cut surface to provide parallel and smooth surfaces for hardness measurements, again using adequate cooling.

4.4.3 After grinding, perform the following to check for possible tempering during the cutting or grinding operation.

(1) Wash sample in hot water.
(2) Etch in 5% Nital solution until black.
(3) Wash in hot water.
(4) Immerse in 50% by volume hydrochloric acid (concentrated) and 50% by volume water for 3 seconds.
(5) Rinse in water and dry.

NOTE: Light or dark areas or streaks indicate that the steel has been tempered by the cutting or grinding operation. This surface condition must be removed before hardness testing.

4.4.4 The center "as-quenched" hardness of the test specimen shall meet the requirements of Paragraph 3.4.7.4.1(4)9 except that hardness test shall be made on as-quenched material without any reheat ing.

4.4.5 A microstructural examination is to be made of the process verification test on cross section adjacent to the surface used for center as-quenched hardness (4.4.4).

Microstructure of the process verification test sample at its center (Figure 1) shall be not less than 90 percent martensite.

NOTE: The requirements of the specification have been determined and set on the basis of a minimum of 90% martensitic structure.

4.5 Quality Assurance Provision: It shall be the prerograt ive of the Fort Worth Division to destructively test and metallurgically examine parts to assure that parts have been processed in accordance with the requirements of this specif i cat ion.

4.6 Rejection: Parts failing to meet the requirements of this specification shall be rejected. Where the failure of any part to meet the requirements of this specification may be attributed to inadequate heat treatment, the part may be reheat treated, in accordance with procedures specified by Fort Worth Division Quality Assurance. (See also Sections 3.1.1 through 3.1.2).

5.0 IDENTIFICATION MARKING

Marking necessary for the identification of sheet or machined parts processed in accordance with this specification shall be applied by the use of non-etching type inks. Metal impression stamps, electro-che mical markings, or any method which creates physical discontinuities on the surface of the steel are not permitted unless specifically required by the engineering drawing.

6.0 RECORDS AND REPORTS

6.1 Records of Test Data and Test Conditions: 'Records shall be made and maintained by the source of all test data and test conditions in meeting the requirements of this specif icat ion.

6.1.1 All test samples and test data (including furnace temperature charts and travelers or routing cards of parts and specimens) are to be suitably identified, readily available for review, and marked in reference to the parts they represent and maintained at the supplier's facility for a minimum of five (5) years. They shall be made available if requested by Fort Worth Division.

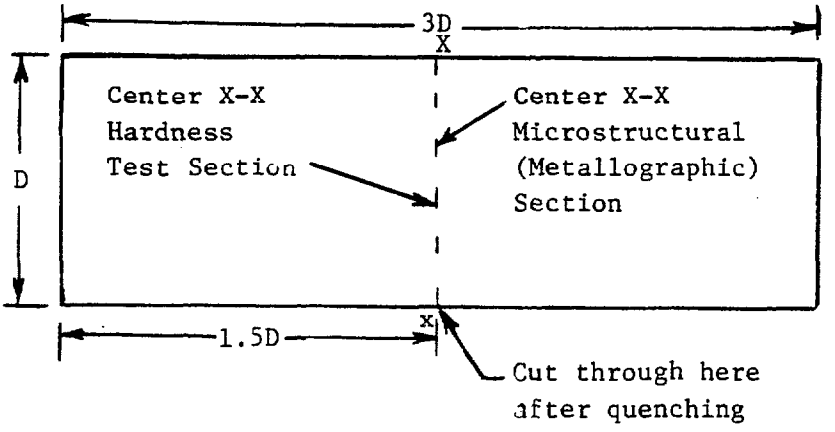
6.1.2 Furnace charts shall be marked with date and operator(s) and identifiable in regard to part number (P/N) and serial number (S/N) of processed items for purposes of valid future record reference. Traveler (operation sheets) shall be dated and signed or stamped by employee(s).

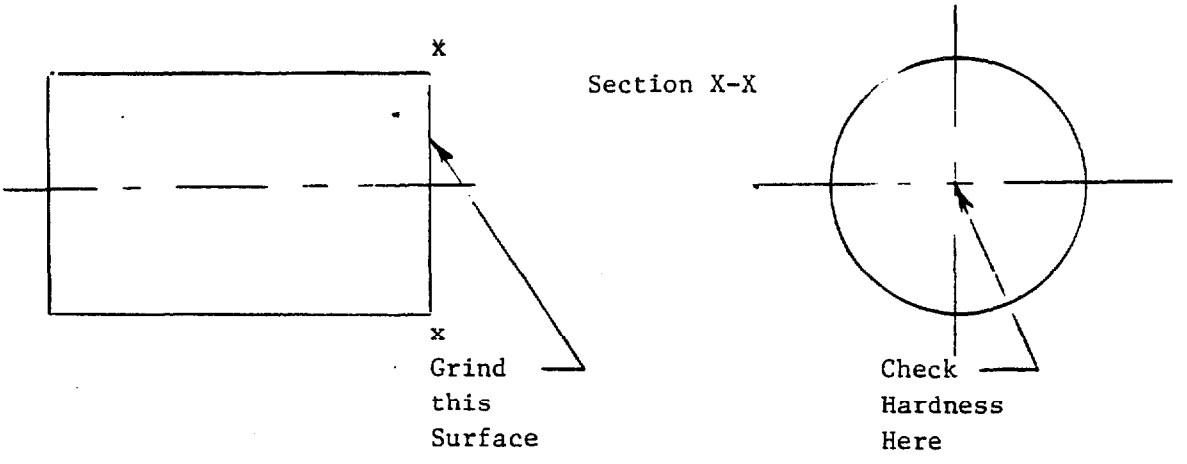
6.2 Reports: With each shipment, a heat treat source shall submit the completed form shown in Figure 3 or suitable equivalent. This form shall include the results of all tests conducted to determine conformance with the requirements of this specification. Tensile test results shall include a reference to the grain direction of the test specimen. Heat treat procedure used (convent ional hardening or Aus-Bay quenching), atmosphere used, and tempering times and temperatures shall be recorded.

7.0 BASIC CRITERIA

The basic criteria throughout this specification are to obtain suitable parts and components having adequate physical and mechanical properties necessary to perform their intended functions. These include the required strength with adequate fracture

toughness and fatigue endurance capabilities as have been considered in developing, and result from, the requirements of this specification. No action is to be taken by anyone, including review and waiver groups or individuals! which operates to defeat this criteria.





D (diameter) = Maximum Equivalent Round of Production Parts Being Processed. (See MIL-H-6875 calculation)

Figure 1

AUS-BAY QUENCH PROCESS VERIFICATION
HARDNESS AND MICROSTRUCTURE TEST SPECIMEN

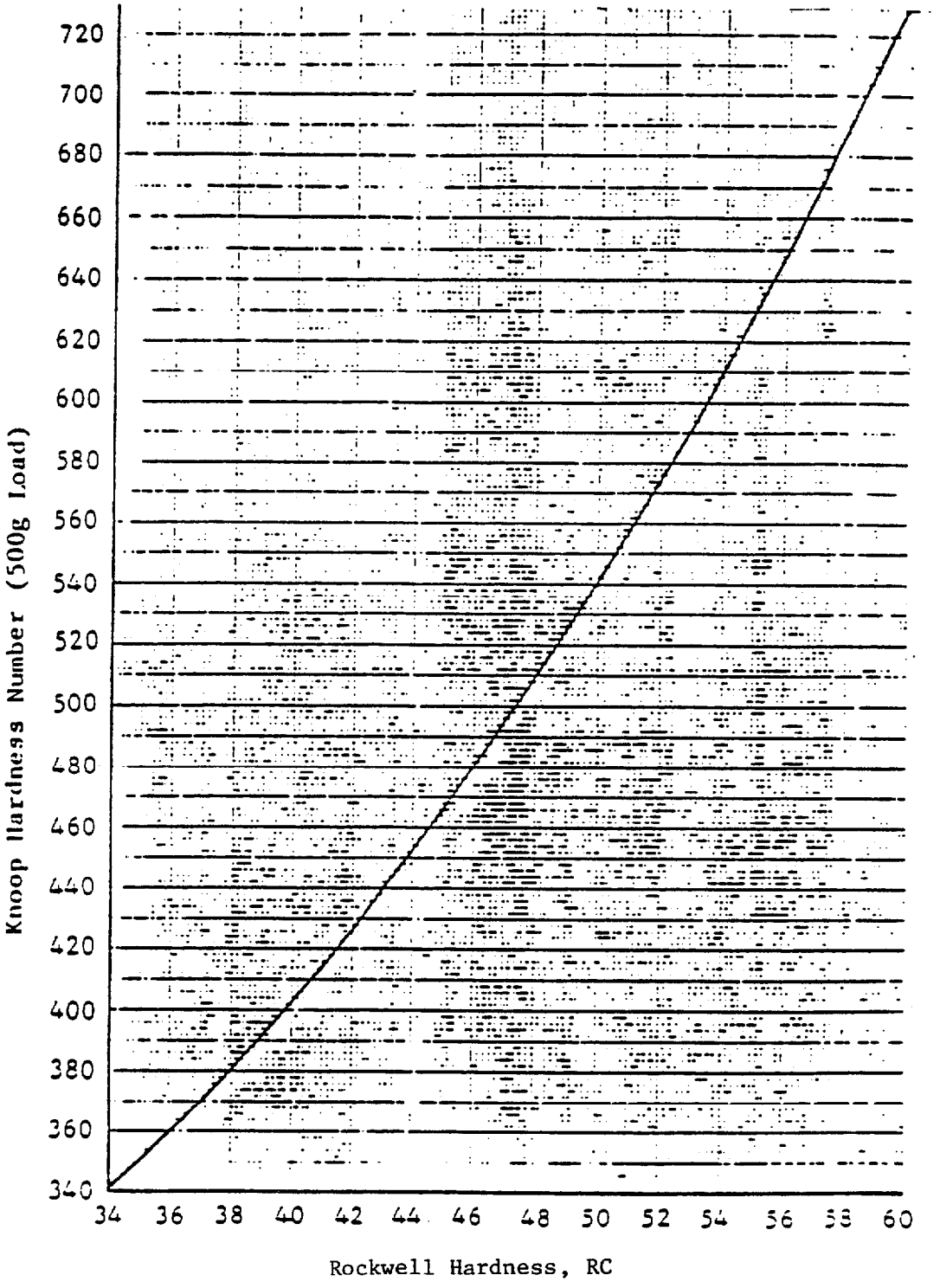


Figure 2

CORRELATION OF KNOOP HARDNESS NUMBERS AND ROCKWELL HARDNESS NUMBERS FOR USE ON D6ac STEEL

GENERAL DYNAMICS
Fort Worth Division

SPECIFICATION: FPS-1029G

VENDOR HEAT TREAT DATA FOR GENERAL DYNAMICS

NOTE: This Form to be Completed by the Heat Treater& Submitted with Each Furnace Load

HEAT TREAT SOURCE (NAME & ADDRESS)	FORT WORTH OPERATION VENDOR (NAME & ADDRESS)

PURCHASE ORDER NUMBER(S):	FORT WORTH OPERATION	VENDOR

PART NUMBER& NAME:

MATERIAL D6-ac	HEAT TREAT SPECIFICATION FPS-1 029 REV _____	NO. OF PIECES IN FURNACE LOAD _____	NO OF PIECES ON PURCHASE ORDER _____

INDICATE OPERATIONS PERFORMED BY COMPLETING REQUIRED DATA:

	FURNACE LOAD NO.	DATE	TEMP (°F)	TIME (HRS)	QUENCH MEDIA	FURNACE ATMOSPHERE
NORMALIZE						
ANNEAL						
STRESS RELIEVE						
HARDENING						
PREHEAT						
AUSTENITIZE						
AUS-BAY						
QUENCH						
SNAP TEMPER						
FIRST TEMPER						
SECOND TEMPER						
THIRD TEMPER						

AS QUENCHED HARDNESS: Thin Section _____ HARDNESS AFTER Thin Section _____

Thick Section _____ SNAP TEMPER: Thick Section _____

TEST BARS: SUPPLIED; YES ❑ NO ❑ REQUIRED; YES ❑ NO ❑

TESTED; YES ❑ NO ❑ GRAIN DIRECTION _____

	ULTIMATE TENSILE STRENGTH	YIELD STRENGTH	% ELONGATION	REDUCTION OF AREA
1				
2				

Figure 3

GENERAL DYNAMICS
Fort Worth Division

SPECIFICATION: FPS-1029G

PART NUMBER _____

DATE _____

No.	Serial Number	Hardness, Rc	No.	Serial Number	Hardness, Rc
1.			11.		
2.			12.		
3.			13.		
4.			14.		
5.			15.		
6.			16.		
7.			17.		
8.			18.		
9.			19.		
10.			20.		

(List Additional Serial Numbers and Results Below Under 'Additional Tests")

Distance From Edge, Inches	Hardness, Rc	DECARBURIZATION - CARBURIZATION TEST - MICROHARDNESS (500g)
.002 .003 .004 .006 .008 .010 CORE		TOTAL DECARBURIZATION: YES ☐ NO ☐ . DEPTH: _____ MICROSCOPIC EXAMINATION PERFORMED AT 100-250X

ADDITIONAL TESTS:

SIGNATURE FOR HEAT TREAT SOURCE	TITLE	DATE

Figure 3 (Continued)

Table I TEMPERING TEMPERATURES AND MINIMUM MECHANICAL PROPERTIES

Tempering Temperature

First Temper	1100°F Minimum		1050°F Minimum		1000°F Minimum		550°F Minimum	
Second Temper	1115°F-1200°F		1095°F-1145°F		1015°F-1060°F		550°F-700°F	
Direction	Longi-tudinal	Trans-verse	Longi-tudinal	Trans-verse	Longi-tudinal	Trans-verse	Longi-tudinal	Trans-verse
Ultimate Tensile Strength, KSI	180 Min 200 Max	180 Min 200 Max	200 Min 220 Max	200 Min 220 Max	220 Min 240 Max	220 Min 240 Max	260 Min 280 Max	260 Min 280 Max
Yield Strength at 0.2% Offset, KSI	163 Min	163 Min	176 Min	176 Min	190 Min	190 Min	215 Min	215 Min
Elongation - % In 4D								
Up to 50 Sq. In.	10	8	9*	8	10.5*	8.5*	7.5	6
Over 50 to 200 Sq. In.	10	9	9*	8	10.5*	7.5*	7.5	6
Over 200 Sq. In.	8	6	7*	6	8.5*	6.5*	6.5	5
Sheet & Plate Under 5/8" thick	8	7	8	7	10	8	6.5	5
Reduction in Area - % (Not applicable to sheet under 1/8" thick)								
Up to 200 Sq. In.	30	25	25*	20	35	25	20	15
Over 200 Sq. In.	25	20	20*	20	30	20	20	15
Hardness	R_c 40-43 BHN 372-400		R_c 43-46 BHN 400-430		R_c 46-49 BHN 430-462		R_c 50.5 - 53 BHN 489-525	

(*Items revised this revision)

GENERAL DYNAMICS
Fort Worth Division
FSCM 81755

Amendment 2 to FPS-1029G
Date: 19 July 1993
Superseding Amendment 1

AMENDMENT TO
FPS-1029G
HEAT TREATMENT, FORGING AND PROCESS REQUIREMENTS
TYPE D6AC STEEL

Contract Number: F33657-84-C-0247

Releasability of this material underthe Freedomof Information Act is subject to restrictions on release in DoD Regulation 5400.7-R and DoD Directive 5230.25.

This amendment incorporated and supersedes all previous amendments. This amendment forms a part of and shall be attached to General Dynamics' Fort Worth Division Specification FPS-102SG, Heat Treatment, Forging and Process Requirements, Type D6aC Steel, dated 21 June 1985. New items this amendment are marked with a vertical bar. This amendment is effective immediately upon issue.

Paragraph

ii Change: Add Table II

Reason: Table II has been added to the document.

2.1 Change: Add the following specification:

QCS-170 Approved Process Sources

Reason: QCS-170 is referenced in the body of the document.

3.1.1 Change: Replace with the following paragraph:

QUALIFICATION PROCEDURES - Heat treat and forging sources shall be those listed in QCS-170.

Reason: Remove Quality Assurance from paragraph.

3.2.6 Change: Replace with the following paragraph:

FURNACE ATMOSPHERE - Furnaces shall be provided with equipment sufficient to maintain the furnace atmosphere so that during heat treatment the surface chemistry changes do not exceed the limits specified in Paragraph 3.4.2.

Reason: Remove Quality Assurance from paragraph.

3.4.2.2 Change: Replace with the following paragraph:

Copper Plating - The requirements of Sections 3.2.5,3.2.6,4.0, and 7.0 apply regardless of the surface chemistry control methods used. In addition, copper plating is required for all parts heat treated in endothermic atmospheres. Copper plating is not required on parts or areas of parts from which at least .020 inch of material is removed from each surface after heat treatment. Atmosphere control specimens and tensile specimens shall not be copper plated. When copper plating is used, it shall be accomplished as follows:

(1) Copper plate per MIL-C-l 4550, Class 1, with the exception that the copper thickness shall be .0005" thick minimum to .001" thick maximum

NOTE: The thickness of plating applies to surfaces which can be touched by a ball 0.75" in diameter. If this cannot be met, the thickness should be sufficient for plating continuity and uniform appearance.

(2) Heat treat as applicable, including quench and final temper.

(3) Strip copper plating using alkaline-sodium cyanide type strippers, such an Enthone, inc., Enstrip "a", Enstrip "s", Enstrip "SCO" or their direct equivalent. Acid and/or elect rolytic stripping methods are strictly prohibited.

(4) Bake at 375 "F ± 25 "F for 24 ± 1 hour to remove entrapped hydrogen.

Reason: Remove Quality Assurance from paragraph.

3.4.6 Change: Replace with the following paragraph:

STRESS RELIEVING (PRIOR TO HEAT TREATMENT) - Detail parts going into weldments which are out-of-flat and weld details that have been cold or totally hot straightened in any manner, shall be stress relieved straightened to the Total Indicator Reading (T.I. R.) flatness requirements of the Engineering Drawing. Stress relieving of non-weld detail parts after cold or locally hot straightening is recommended but is not mandatory. Stress relieving shall be accomplished by heating the part to 1175 'F ± 25 "F and holding for one hour or one hour per inch of thickness, whichever is greater. Cool in still air. Refer to FPS-1 033orFPS-1095 for temperatures and times for complete weld assemblies.

NOTE: The purpose of stress relieving is to remove the residual stresses in parts resulting from forging, machining, forming, straightening, heat processing, welding, etc., to minimize the effect on subsequent operations, such as subsequent welding and/or heat treatment. Finished machined parts that meet the flatness requirements of the Engineering Drawing, unrestrained, do not require stress relief. It is recommended that large parts be rough machined, stress relieved and subsequently finished machined.

Reason: Remove Quality Assurance from paragraph.

3.4.7.2 Change: Replace with the following paragraph:

Tensile Coupons - When tensile coupons are required in accordance with Paragraph 4.1, they shall accompany parts through all heat treating processes and not be thermally processed separately.

Reason: Remove Quality Assurance from paragraph.

3.4.7.3 Conventional Hardening and Tempering

(1) Austenitizing: Heat part to 1700 "F+ 25 "F and soak at temperature not less than 1/2 hour or 1/2 hour per inch of maximum section thickness, whichever is greater. Preheating to 1200 "F maximum is permissible.

(2) Quenching: Quench into agitated oil or agitated salt followed by air cooling to below 150 "F. For parts thicker than a two-inch equivalent round, quench into agitated oil at 140 *F ± 10 "F. Consult MIL-H-6875 to determine equivalent round sizes. For thinner parts, either an agitated oil or agitated molten satt quench maybe used.

(A) The salt shall be molten at a maximum of 400 'F. After air cooling to below 150 'F, rinse in hot water until all traces of the quench salt are removed.

(B) The oil quenching temperature shall be 130 'F to 200 "F.

The "as-quenched or "as-quenched and stress relieved" hardness of representative parts shall meet the requirements of Paragraph 3.4.7.4.1 (4).

(3) Tempering: If a delay sufficient to initiate cracking is anticipated before the first tempering operation, stress relieve for a minimum of 2 hours at a temperature of 375 'F to 450 "F. The tempering operations shall be performed in accordance with Table I for the strength level specified on the engineering drawing. Each tempering operation shall be for a minimum of 2 hours or 1 hour per inch of maximum section thickness, whichever is greater, followed by air cooling to room temperature. Final machining and/or grinding operations should be performed between tempering operations when possible.

The vendor may use the following alternate tempering procedures at his option:

(1) First temper shall be 550 "F minimum for 2 hours or 1 hours per inch of thickness, whichever is greater.

(2) Second temper shall be as specified in Table 1 for the required strength level and shall not be less than 2 hours or 1 hour per inch of thickness, whichever is greater.

Reason: Remove Quality Assurance from paragraph.

3.4.7.5 Change: Replace with the following paragraph:

Aus-Bay Quench Process Verification Test - A process verification test specimen shall be processed prior to initial heat treat loads Aus-Bay quenched and under maximum production heat treat load weight and cross section size conditions. The test specimen and test procedures shall conform to Figure 1 and paragraph 4.4. When changes in maximum furnace loads or section sizes are made, this test must be repeated. All test conditions and data results are to be reported per paragraph 6.0.

Reason: Remove Quality Assurance from paragraph.

4.1.1.2 Change: Remove paragraph 4.1.1.2.

Reason: Remove Quality Assurance from paragraph.

4.2 Change: Replace with the following paragraph:

HARDNESS TEST - Each part shall be hardness tested per NDTS 1500. Hardness values shall meet the requirements of Table 1. All hardness test results for parts and test specimens shall be reported on the SOIR or equivalent paperwork

Reason: Parts and lots do not need to be serial numbered.

4.3 Change: Replace with the following paragraph:

SURFACE CHEMISTRY CHANGE EXAMINATION - A minimum of 1 atmosphere control specimen shall be austenitized with each heat treat load. Prior to heat treatment, the specimen reference surfaces shall be clean and free from all surface decarburization and contamination. Specimen configuration is optional. An as-heat treated section from a broken tensile specimen per 4.1 may be used when available if the tensile specimen was finished machined prior to the treatment. Additional processing shall be as follows:

(1) The atmosphere control specimen shall be tempered to the same heat treat level as the parts. Specimen(s) shall not be cleaned in any manner that will prevent accurate determination of surface chemistry changes which occur during processing.

(2) The specimen shall be prepared for microhardness testing and metallographic examination using proper mounting/polishing procedures to insure flat edge retention.

(3) Microhardness testing to evaluate surface chemistry variations shall be accomplished in accordance with ASTM E 384. A 500 gram load shall be used for microhardness testing. The specimen shall meet the equivalent Rockwell C hardness values specified in Table II based on the conversion from Knoop Hardness Number to R_c value shown in Figure 2.

(4) The criteria in (3) above have been established to determine surface chemistry changes caused by improper furnace atmosphere control. Specimens which fail to meet the requirements shall be retested. Acceptance shall be based on a review by a GD/FW Metallurgist. If the failure was caused by surface chemistry changes, all parts represented by the test specimens shall be rejected. If the microhardness shows an "under-tempered condition, not detectable by surface hardness testing, the parts represented by the specimen maybe retempered.

(5) The test specimen shall be examined metallographically at IOOX to 250X magnification for total decarburization. The entire heat treat bad represented by the specimen tested shall be rejected if the test specimen shows complete depletion of carbon at any depth.

(6) All microhardness test data shall be reported. The mounted specimens which were tested shall be suitably identified and maintained at the supplier's facility. They shall be made available if required by GD/FW.

(7) In case of question, a specimen may be removed from a part from an area designated by Engineering as "non-critical" and used for the test required in this paragraph. The specimen shall be reviewed by a GD/FW Metallurgist. Data from this specimen takes precedence over data obtained from the atmosphere control specimen or a broken tensile specimen.

Reason: Remove Quality Assurance from paragraph.

4.6 Change: Replace with the following paragraph:

REJECTION - Parts failing to meet the requirements of this specification shall be rejected. Where the failure of any part to meet the requirements of this specification may be attributed to inadequate heat treatment, the part maybe reheat treated, in accordance with sections 3.1.1 through 3.1.2.

Reason: Remove Quality Assurance from paragraph.

6.2 Change: Replace with the following paragraph:

REPORTS - Reports containing the information shown in Figure 3 shall be made for each shipment. This report shall include the results of all tests conducted to determine conformance with the requirements of this specification. Tensile test results shall include a reference to the grain direction of the test specimen. Heat treat procedure used (conventional hardening or Aus-Bay quenching), atmosphere used, and tempering times and temperatures shall be recorded. These reports shall be maintained at the supplier's facility for a minimum of five years.

Reason: Reports shall be maintained at the supplier's facility.

TABLE II: Microhardness to Rockwell Conversion

DISTANCE FROM EDGE, INCHES	HEAT TREAT RANGE			
	180-200 KSI	200-220 KSI	220-240 KSI	260-280 KSI
.002	Rc 36 -~)	Rc 39- (*)	Rc 42 -~)	Rc 46 - (*)
.003	38- (')	41- (*)	44 - (*)	48 - (*)
.004	40- (*)	43- (*)	46- (*)	50.5- (*)
.006	40- (*)	43- (*)	46- (*)	50.5- (*)
.008	40- (*)	43- (*)	46- (*)	50.5- (*)
.010	40- (*)	43- (*)	46- (*)	50.5- (*)
Core	40-43	43-46	46-49	50.5-53

(*) The maximum hardness shall not exceed the core hardness by more than one point Rc.

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