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Abstract

We investigated the suitability of using readily available ("off-the-shelf"), as opposed to made-to-order, AISI 4340 steel for the production of NIST reference Charpy specimens of low- and high-energy levels. This study was preceded by technical discussions inside and outside NIST, which led to the streamlining and simplification of the technical specifications for the procurement of 4340 steel, as well as 9310 steel (used for the production of super-high-energy reference specimens). Charpy tests were performed on the three reference machines in Boulder, on trial lots of 75 specimens, heat-treated and machined according to the same procedures used by our current Vendors for reference specimens. Four of the six "off-the-shelf" 4340 steel heats were found immediately acceptable according to the NIST criterion (sample size ≤ 5.0). The remaining two heats yielded sample sizes between 5 and 6, and after re-tempering and machining the few remaining blanks, the corresponding Charpy tests provided acceptable sample sizes (between 2-4). The outcome of this investigation supports the validity of our revised steel specifications and the acceptability of "off-the-shelf" 4340 steel batches for the Charpy Machine Verification Program.

Keywords

AISI 4340 steel; "off-the-shelf" steel; reference Charpy specimens; sample size; steel specifications.

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1. Introduction

Since 1989 [1], the Charpy Machine Verification Program at NIST in Boulder, Colorado, has provided thousands of companies in more than 60 countries worldwide with certified reference Charpy specimens for the indirect verification of their machines according to ASTM E23 [2] and ISO 148-2 [3]. NIST took over the Program from the US Army that started it during the 1960s at the Watertown Arsenal in Massachusetts [4].

Reference Charpy specimens are produced at three absorbed energy levels: low (typically, 15 J to 20 J), high (80 J to 120 J), and super-high (190 J to 230 J). For the first two energy levels, NIST uses AISI 4340 steel, heat treated according to different procedures in order to attain the desired Charpy absorbed energy, as well as low variability; for super-high energy specimens, 18 Ni maraging steel (type T-200) was used until the mid-2010s, and currently AISI 9310 steel is employed [5].

Steel 4340 is a medium-carbon-nickel-chromium-molybdenum steel alloy with excellent tensile strength, toughness, and fatigue resistance. Primarily because of its toughness, 4340 steel finds use in heavy machinery, specifically for the manufacturing of transmission parts, such as heavy-duty shafts, gears, and axles. Other uses include the military industry – both for ground vehicles and military aircraft, the commercial aircraft industry (landing gear), various automotive uses, rocket motor cases, pressure vessels, fasteners, ordnance hardware, etc. The typical chemical composition of the steel is shown in Table 1 [1].

Table 1 - Composition of 4340 steel (mass %).

C	Si	Mn	Ni	Cr	Mo	S	P
0.4	0.28	0.66	1.77	0.83	0.28	0.001	0.004

In the past, NIST purchased 4340 and 9310 steels in the form of square bars with side = 0.5 in. (12.7 mm). However, it was recently decided to switch to more readily available round bars with diameter between 5/8 in. – 1 in. (15.9 mm – 25.4 mm). The possibility of using larger diameter round bars, and extracting multiple specimens within the cross section, will be investigated during FY 2025.

The absorbed energy of 4340 steel Charpy specimens primarily depends on the final tempering temperature, as seen in Figure 1 [1]. Namely, low-energy levels are attained by tempering between 300 °C – 400 °C. For high-energy specimens, final tempering should be performed near 600 °C. In all cases, the microstructure of the specimens must be 100 % tempered martensite.

The heat treatment originally recommended by the Army Materials Technology Laboratory is shown in Table 2 [4].

Table 2 - 4340 steel heat treatment recommended by the US Army in the early years of the Charpy Program.

Low-energy specimens	High-energy specimens
Normalization at 900 °C (1650 °F) for 1 h, air cool	Normalization at 900 °C (1650 °F) for 1 h, air cool
Hardening at 871 °C (1600 °F) for 1 h, oil quench	Hardening at 871 °C (1600 °F) for 1 h, oil quench
Tempering at 400 °C (750 °F) for 1.5 h, oil quench	Tempering at 593 °C (1100 °F) for 1.5 h, oil quench

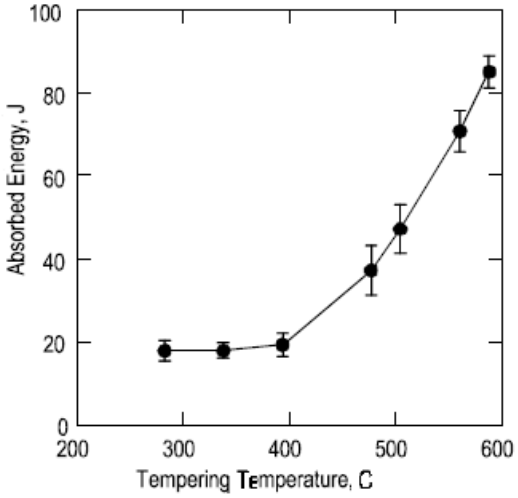

Figure 1 - Influence of final tempering temperature on the Charpy absorbed energy of 4340 steel [1].

The exact heat treatment for reference Charpy specimens of any energy level is, however, established by our specimen suppliers, in agreement with their heat treater. NIST does not provide specific guidelines, and determines the acceptability of a lot (batch) of reference specimens only based on the statistical analysis of the certification test results [6].

Since the start of the Charpy Program, low- and high-energy specimens have been tested at -40 °C (-40 °F). Only recently, NIST has decided to certify specimens of both energy levels at ambient temperature (21 °C).

This decision has not affected the heat treatment of high-energy specimens, since they are in upper shelf (fully ductile) conditions at both -40 °C and 21 °C. However, in the case of low-energy specimens, the higher impact toughness caused by the higher test temperature increases the likelihood of jamming between broken specimen halves and test machine parts (anvils, supports, swinging hammer). An investigation was recently completed to identify a revised final tempering temperature that reproduces at 21 °C the same toughness conditions previously displayed by low-energy specimens at -40 °C [7].

2. Recent changes in the NIST specifications for 4340 and 9310 steels

In the last two decades, the NIST Charpy Machine Verification Program purchased every two to three years steel that was custom ordered, in the form of square cross section bars. Steel was ordered in accordance with relatively strict specifications, formulated in the late 1990s/early 2000's. This version of the specifications, which is reproduced in Appendix A, made it unlikely that fully compliant 4340 and/or 9310 steel would be readily available in the open market. Steels had to be produced by steel mills through a steel broker, and delivery times were typically in the order of one to two years. As mentioned above, steels were purchased in the form of square bars, which are also less available than bars with round cross-section.

It was therefore felt that specifications were too restrictive, and might be somewhat simplified without compromising the quality of the finished product (Charpy reference specimens). During FY 2023, through technical discussions inside NIST and interactions with various steel brokers, it was decided to simplify and streamline the specifications, in order to

increase the likelihood of locating acceptable steels in the open market ("off-the-shelf" steels), while retaining specific features that were considered essential for the quality of the finished product, namely:

- Steel production process.
- Chemical composition.
- Grain size.
- Bar hardness (HRC and HV).

Specifically, the last two properties (grain size and hardness) were found to be deciding factors in distinguishing between "good" and "bad" 4340 steel heats, based on an investigation conducted in 2021 [8]. It was concluded that "*the most reliable indicator of the difference between the two steel batches resulted from the measurement of grain size based on microstructural analyses.*" Additionally, "*These observations can be supported by HRC and HV measurements, which are also relatively fast and inexpensive.*" The expected properties for a "good" 4340 steel heat are: grain size in the range 30 μm – 40 μm (ASTM number > 7) and Vickers hardness in the range $200 \leq HV \leq 210$.

The revised NIST specifications for 4340 and 9310 steel heats are provided in Appendix B. The main changes with respect to the previous version (Appendix A) are listed below:

(a) The following sentence was added: "*Other [steel production] processes may be considered, provided they are deemed suitable for the aims of the NIST Charpy program.*"
(b) For 4340 steel, the maximum allowable S content was increased from 0.01 % to 0.04 %.
(c) The requirement to measure the composition at the top and bottom of the re-melted ingot, with specified maximum allowed differences between the two measurements, was replaced by a recommendation ("*Preference will be given to heats where the compositions at the top and bottom of the ingot are available.*").
(d) The processing requirements for the ingots were considerably simplified.
(e) The cross-section of the bars was changed from 0.5 in. (12.7 mm) square to round, with diameter between 0.625 in. – 0.875 in. (15.9 mm – 22.2 mm).
(f) An error in the grain size requirement[1] ("*maximum acceptable grain size of ASTM number 7*") was rectified ("*ASTM grain size No. 7 or finer*").
(g) Maximum hardness requirements for the bars were slightly modified (from HRB = 95 to HRB = 100), and the corresponding limits according to different hardness scales (HV, HRC, HB) were added.

As a result of adopting simpler specifications, it will be possible in the future to purchase 4340 and 9310 steels in "off-the-shelf" format, without having them made-to-order by steel mills in strict compliance with our specifications.

The investigation reported herein was conducted to validate the revision of the specifications and confirm the acceptability of using "off-the-shelf" 4340 steel for the production of low- and high-energy Charpy reference specimens. Small quantities (5-6 bars) from several "off-the-shelf" 4340 heats were purchased, and trial lots of 75 Charpy specimens per heat were produced by one of our qualified Vendors. Specimens were tested on the three NIST reference machines under conditions equivalent to ordinary certification tests, and the results were

[1] According to ASTM E112, the higher the ASTM number, the finer is the grain size.

statistically analyzed to confirm the acceptability of the heats according to NIST requirements [1].

3. Preliminary tests: low-energy specimens from Heat J4905

The first "off-the-shelf" heat of 4340 steel examined in 2024 was Heat J4905, produced by Carpenter Technology (Latrobe, PA). The Certificate of Tests provided by the steel maker is reproduced in Appendix C. The information provided fulfils the requirements of the revised NIST specifications (Appendix B). In particular, grain size is given as ASTM numbers 7.5 and 8 in two different locations (NIST minimum = 7), and Rockwell C hardness is reported as 23.9 and 21.9 in two different locations (NIST maximum = 24).

Two round bars with diameter = 0.625 in. (15.875 mm) and length ~ 12 ft (3.66 mm) from Heat J4905 were purchased and shipped to one of our Vendors, who proceeded to prepare 73 Charpy specimens, a number close to the standard amount (75) for a reference lot (pilot or production). The heat treatment used by the Vendor was identical to that used previously in the preparation of reference low-energy specimens.

The 73 specimens were tested at 21 °C ± 1 °C on the three Charpy reference machines (SI, TO, and TK) located at NIST in Boulder, Colorado. Before the tests, Rockwell C hardness measurements were performed on 30 randomly selected samples. The overall test results are presented in Table 3, while individual measurements are reported in Appendix D.

Table 3 – Overall Charpy and hardness test results on low-energy specimens from Heat J4905.

Parameter	Absorbed energy (J)	Hardness HRC
Number of tests	73	30
Mean	19.21	46.15
Standard deviation	0.75	0.30
Standard error	0.09	0.05
Minimum	17.40	45.20
Maximum	20.42	46.50
Range	3.02	1.30
Coefficient of variation[2]	3.9 %	0.6 %

The acceptability of a Charpy reference lot depends on the value of a specific statistical parameter, the sample size n_{SS} [1]:

$$n_{SS} = \left(\frac{3s_p}{E}\right)^2 \quad , \tag{1}$$

where the pooled standard deviation, s_p, is given by:

$$s_p = \sqrt{\frac{s_1^2+s_2^2+s_3^2}{3}} \quad , \tag{2}$$

with s_1, s_2, s_3 = standard deviation of the three reference machines, and E = larger between 1.4 J and 5 % of the mean absorbed energy. The reference Charpy lot is considered acceptable if $n_{SS} \leq 5.0$.

[2] The coefficient of variation is the ratio between standard deviation and mean absorbed energy, expressed in percent.

For the test lot obtained from Heat J4905, n_{SS} = 1.145, and therefore the heat is considered suitable for the production of NIST reference Charpy specimens.

4. Additional validation tests: high-energy specimens from five "off-the-shelf" 4340 steel heats (J4906, J4943, J5385, J5803, J6489)

After the favorable outcome of the investigations on the first "off-the-shelf" heat of 4340 steel, we purchased a few round bars of five additional 4340 heats, all compliant with our revised specifications. For these five heats, all produced by Carpenter Technology, bar diameter, grain size, and Vickers hardness obtained from the respective Certificate of Tests (reproduced in Appendix E – Appendix I) are summarized in Table 4.

Table 4 – Main characteristics of five "off-the-shelf" heats of 4340 steel.

Heat No.	Bar diameter (in.)	Grain size (ASTM No.)	Hardness HRC
J4906	0.625	8.0	21.7, 20.3
J4943	0.625	8.0	22.1, 20.6
J5385	0.625	8.5	21.4, 23.0
J5803	0.625	8.5	22.4, 21.0
J6489	0.760	8.0	23.2, 21.5

The purchased bars were shipped to the same Vendor, and this time 75 high-energy Charpy specimens per heat were produced according to standard procedures (including heat-treatment conditions). All specimens were then tested at 21 °C on the three NIST reference machines, and results were statistically analyzed as previously described. Rockwell C hardness measurements on 10 randomly selected specimens per heat were also performed. Overall Charpy test results for the five heats are collected in Table 5. Individual hardness measurements and Charpy absorbed energies for the five heats are collected in Appendix J.

Table 5 – Overall Charpy test results on high-energy specimens from five "off-the-shelf" 4340 steel heats.

Heat No.	J4906	J4943	J5385	J5803	J6489
Number of tests	75	75	75	75	75
Mean (J)	118.07	122.00	118.72	119.88	122.27
Standard deviation (J)	3.43	4.21	4.85	4.09	4.63
Standard error (J)	0.40	0.49	0.56	0.47	0.54
Minimum (J)	109.85	113.19	107.84	105.68	111.46
Maximum (J)	127.42	131.15	129.66	130.87	135.25
Range (J)	17.57	17.96	21.82	25.19	23.79
Coefficient of variation	2.9 %	2.9 %	4.1 %	3.4 %	3.8 %
Sample size, n_{SS}	**2.183**	**2.922**	*5.976*	**4.225**	*5.170*

As shown in the last row of Table 5, three of the heats resulted acceptable based on the calculated values of sample size ($n_{SS} \leq 5.0$, highlighted in **bold**). The remaining two, J5385 and J6489, failed the acceptance criterion, but their n_{SS} (highlighted in *italic*) was found to be between 5 and 6, and therefore relatively close to the acceptance threshold.

Since it's a relatively common occurrence (about 30 % of the times, according to our Vendor) that a lot of reference Charpy specimens must be re-tempered a second time before passing the acceptance criterion, we decided to ask our Vendor to perform a re-tempering of the

remaining blanks[3] from heats J5385 (15 blanks) and J6489 (6 blanks), which were then machined into Charpy specimens.

The retempered specimens were tested on one of the reference machines (TO), and the results (reported in Appendix K, along with hardness measurements) were compared with those obtained on the TO machine from the original specimens from heats J5385 and J6489. Clearly, the test numbers were significantly lower (25 vs. 15 and 6), but the calculated sample sizes before and after re-tempering can at least suggest whether data variability improved as a result of re-tempering.

The results from the TO tests on the original and re-tempered specimens from heats J5385 and J6489 are summarized in Table 6.

Table 6 – Overall Charpy test results on the original and re-tempered high-energy specimens from heats J5385 and J6489. Acceptable sample sizes are highlighted in **bold**, unacceptable in *italic*.

Heat No.	J5385		J6489	
	Original	Re-tempered	Original	Re-tempered
Number of tests	25	15	25	6
Mean (J)	117.54	119.44	121.85	121.23
Standard deviation (J)	5.02	3.81	4.40	2.86
Standard error (J)	1.00	0.99	0.88	1.17
Minimum (J)	107.84	112.81	112.82	115.79
Maximum (J)	127.43	127.17	130.96	124.02
Range (J)	19.59	14.36	18.14	8.23
Coefficient of variation	4.3 %	3.2 %	3.6 %	2.4 %
Sample size, n_{SS}	*6.556*	**3.670**	**4.684**[4]	**2.002**

For both heats, re-tempering causes a clear decrease of sample size, indicating a lower variability. Although it's not possible to establish whether a full re-tempered trial lot of 75 specimens would have become acceptable, this appears certainly possible based on the limited available data in Table 6.

5. Conclusions

Six "off-the-shelf" (*i.e.*, readily available, not made-to-order) heats of AISI 4340 steel, fulfilling the recently revised and simplified NIST specifications, were assessed for acceptability by performing Charpy tests on the three reference machines in Boulder, Colorado. Specimens were manufactured by one of the NIST Vendors following the procedures always used for reference specimens, and tested and analyzed in the same fashion as for the official certification of Charpy reference specimens. For four of the six heats, calculated sample sizes were lower than 5.0, which is the maximum acceptable value according to the NIST certification procedures. For the remaining two heats, the original sample sizes were unacceptable, but relatively close to the limit (between 5-6). A re-tempering of the remaining Charpy blanks for these two heats showed a considerable improvement/reduction of sample size, although the number of tests was much lower than for a conventional lot (75).

The outcome of this study validates the possibility of purchasing "off-the-shelf" 4340 steel, as long as it is compliant with the NIST specifications, for the production of low- and high-

[3] A blank is an oversized, unnotched Charpy specimen (bar) that is heat treated before being final machined to the required dimensions.
[4] As a reminder, heat J6489 had originally failed considering all three machines (n_{SS} = 5.170, see Table 5), but had an acceptable sample size (n_{SS} = 4.684) if only the TO machine was considered.

energy reference Charpy specimens. It also provides substantial support to the simplification of the NIST steel specifications, which was accomplished in FY 2024.

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Appendix A. Previous version of NIST 4340 and 9310 steel specifications (2019)

Specifications

4340 steel

Compositional and melting requirements

1. The Contractor shall provide AISI 4340 steel bars, from a single heat to minimize compositional and microstructural variation. Because steel plants produce steel in different heat sizes (inherent to their facilities), ACMD will allow some flexibility in our contract by bracketing the quantity of the steel to be purchased and setting a maximum of $100,000 for the purchase. We prefer to purchase the maximum quantity of steel possible.
2. The steel shall be produced using either a double-vacuum-melting procedure (vacuum-induction-melt vacuum-arc-remelt, VIM-VAR), or arc furnace melting followed by argon-oxygen-decarburization (AOD) refining to produce electrodes which are vacuum arc re-melted (ARC-AOD-VAR).
3. The steel shall meet the compositional requirements of AISI-SAE alloy 4340. Refer to http://www.steelforge.com/alloy-steel-4340/ for compositional information.
4. The steel must also meet the stricter requirements of AMS6414 (see http://standards.sae.org/ams6414/), which describes steel production by a vacuum-melting procedure.
5. ACMD also requires that the phosphorus, sulfur, vanadium, niobium, titanium, and copper contents of the steel to be low. The maximum concentrations (in mass %) allowedfor these elements shall be: (1) P = 0.010, (2) S = 0.010, (3) V = 0.030, (4) Nb = 0.005, (5) Ti = 0.003, and (6) Cu = 0.35.
6. The composition shall be certified using standard analytical procedures (such as optical emission spectroscopy or x-ray fluorescence), and the equipment shall be calibrated by standards traceable to NIST. The composition shall be measured at the top and bottom of the re-melted ingot. These two measurements shall be included in the documentation withthe order, meet our compositional requirements, and meet the limits on residuals given in 5. above. Deviations between the two measurements (in mass percent between the top and bottom of VAR ingot) cannot exceed 0.030 for C, Si, and Mo; 0.10 for Mn; 0.030 forCr; 0.050 for Ni; 0.003 for P; and 0.001 for S.
7. The ingots shall be forged, rolled to billet, conditioned, then hot rolled to bar (if an alternate process has not been mutually agreed upon). The goal of the processing is to have bar from one procurement to have inclusion distributions and sizes that are similar to batches produced from other procurements. With this objective in mind, it is required that the steel be processed in a manner agreed upon prior to the processing of the steel, such as:
    a. VAR ingots at 1093 °C (2000 °F) are forged to 12 by 11 inch billets that are rolled to 2 ¼ inch diameter billets.
    b. These billets are then solution annealed (1100 °C/2012 °F for 1 hour, minimum)

prior to rolling to ½ inch square bar (1093 °C/2000 °F).

c. If the solution treatment is performed as a separate process, controlled cooling (fans, quenching, etc.) is required down to a temperature of 500 °C (930 °F).
d. If the solution treatment is performed as part of the re-heating cycle prior to rolling, the process shall be described in adequate detail to indicate/estimate holding and cooling times.

8. The bar shall be finished to 0.50-inch square bar (+0.15 inch, -0.00 inch).
   a. The corner radius of the finished bars cannot exceed 0.03 inches.
   b. The microstructure shall be uniform through the thickness, with a maximum acceptable grain size of ASTM number 7.
   c. In other attributes (decarburization, segregation, surface condition, etc.), the steel must be suitable for use as 10 mm square Charpy V-notch specimens.
9. The 0.50-inch bar shall be fully annealed to a hardness of RB-95 max.
   a. The bar shall be annealed at 850 °C (1550 °F) for 1 hour, furnace cooled at 10 °C/hr (50 °F/hr) to 315 °C (600 °F), then air cooled to room temperature.
   b. It is critical to produce a uniform hardness bar (no hard spots), because hard spots result in significant machining issues.
   c. ACMD will accept alternate heat-treating schedules by mutual agreement.

The bars shall be machine straightened (for twist and bow), and shipped in lengths of no more than 6 feet.

9310 steel

Compositional and melting requirements

All AISI 9310 (AMS 6265) bars shall come from a single heat, to minimize compositional and microstructural variations. The steel shall be produced from a single master heat using electric arc furnace melting procedures, followed by argon-oxygen decarburization refining (AOD) and then vacuum arc remelting (VAR).

The steel shall meet the compositional requirements of AMS 6265M (see Table below), with the following exceptions. The phosphorus, sulfur, and copper shall have the following maximum limits: $P \leq 0.010$, $S \leq 0.010$, $Cu \leq 0.20$, $V \leq 0.030$, $Nb \leq 0.005$, and $Ti \leq 0.003$ (all in mass %). No limitations on V, Nb, and Ti are not included in AMS 6265M. These three elements shall be analyzed by an independent laboratory designated by NIST. NIST will have the option to accept or reject the material based on any deviation from the above-mentioned specifications for V, Nb, and Ti.

Chemical composition, mass %		
	Min	Max
C	0.07	0.13
Si	0.15	0.35
Mn	0.40	0.70
P		0.010
S		0.010
Cr	1.00	1.40
Mo	0.08	0.15
Ni	3.00	3.50
B		0.001
Cu		0.20
Nb		0.005
Ti		0.003
V		0.030

The composition shall be certified using standard analytical procedures, such as optical emission spectroscopy or x-ray florescence, and the equipment is to be calibrated by standards traceable to NIST.

Processing requirements

The VAR ingots shall be forged, rolled to billet, conditioned, then hot rolled to bar (if an alternate process has not been mutually proposed.) The bar shall be finished to 0.50" square bar (+0.15", -0.00") and straightened. The corner radius of the finished bars cannot exceed 0.03".

The microstructure shall be uniform through the thickness, with a maximum grain size of ASTM number 7. In other attributes (decarburization, segregation, surface condition, etc.), the steel must be suitable for use as 10 mm square Charpy V-notch specimens.

The 0.50" bar shall be annealed to a maximum hardness of RB-95. The goal here is to produce bars with a minimum of large carbides in the structure, the most uniform carbide precipitation possible, and a uniform hardness.

The bars shall be machine straightened (for twist and bow), and shipped in lengths of no more than 6 feet.

Appendix B. Current (revised) version of NIST 4340 and 9310 steel specifications (2024)

NIST Charpy Program Steel Specifications

4340 steel

The Contractor shall provide AISI-SAE 4340 steel bars from a single heat, in order to minimize compositional and microstructural variations.

The steel shall be produced using either a **double-vacuum-melting procedure** (vacuum-induction-melt vacuum-arc-remelt, **VIM-VAR**) or **(electric) arc furnace melting**, followed by argon-oxygen-decarburization refining to produce electrodes which are **vacuum arc re-melted** (**EAF/ARC-AOD-VAR**). Other processes may be considered, provided they are deemed suitable for the aims of the NIST Charpy program.

The steel shall meet the compositional requirements of AISI-SAE alloy 4340 (https://www.azom.com/article.aspx?ArticleID=6772), as well as the stricter requirements of AMS6414 (https://www.sae.org/standards/content/ams6414n/), which describes steel production by a vacuum-melting procedure, and the maximum limits required by NIST for specific elements, if reported (P, S, V, Nb, Ti, Cu, O, N). The overall chemical composition requirements are summarized in Table below.

Table 1 - Chemical composition requirements (mass %) for 4340 steel.

C	Cr	Mn	Mo	Ni	P	Si	S	Cu	V	Nb	O	N
0.38-0.43	0.70-0.90	0.65-0.80	0.20-0.30	1.65-2.00	≤ 0.010	0.15-0.35	≤ 0.04	≤ 0.35	≤0.030	≤0.005	≤0.0025	≤0.0025

If the chemical compositions at the top and bottom of the re-melted ingot are available, the differences between the two measurements (in mass percent) shall not exceed 0.030 for C, Si, and Mo; 0.10 for Mn; 0.030 for Cr; 0.050 for Ni; 0.003 for P; and 0.001 for S. Preference will be given to heats where the compositions at the top and bottom of the ingot are available.

The ingots shall be either hot-rolled to bar, or (preferably) annealed and cold-drawn/cold-finished.

The round bars shall be finished to a diameter between 0.625 in. (15.9 mm) and 0.875 in. (22.2 mm), with preference given to lower diameters.

The microstructure shall be uniform through the thickness, with an ASTM grain size No. 7 or finer, determined in accordance with ASTM E112.

The bar hardness shall not exceed HRB = 100, HV = 252, HRC = 24, or HB = 245 (depending on the hardness scale used).

In order to avoid twist and bow, the bars shall be either vertically hung during the heat treatment (vertical heat treatment - preferred method), or machine straightened.

The amount ordered shall be between 1,200 lbs. – 10,000 lbs., with preference given to quantities of 3,500 lbs. and above.

The bars shall be shipped in lengths of no more than 6 feet, and shall be securely packaged in boxes weighing no more than 2,500 lbs. each.

9310 steel

The Contractor shall provide AISI 9310 (AMS 6265) bars from a single heat, in order to minimize compositional and microstructural variations.

The steel shall be produced using **(electric) arc furnace melting procedures**, followed by **argon-oxygen decarburization refining** and then **vacuum arc remelting** (EAF/ARC-AOD-VAR). Other processes may be considered, provided they are deemed suitable for the aims of the NIST Charpy program.

The steel shall meet the compositional requirements of AISI alloy 9310 (https://www.azom.com/article.aspx?ArticleID=6703), as well as the stricter requirements of AMS 6265 (https://www.ssa-corp.com/en/9310-AMS-6265-UNS93106.php), and the maximum limits required by NIST for specific elements, if reported (P, S, V, Nb, Ti, Cu). The overall chemical composition requirements are summarized in Table below.

Table 2 - Chemical composition requirements (mass %) for 9310 steel.

C	Cr	Mn	Mo	Ni	P	Si	S	Cu	V	Nb	Ti
0.07-0.13	1.00-1.40	0.40-0.70	0.08-0.15	3.00-3.50	≤ 0.010	0.15-0.35	≤ 0.010	≤ 0.20	≤0.030	≤0.005	≤0.003

The ingots shall be either hot-rolled to bar, or (preferably) annealed and cold-drawn/cold-finished.

The round bars shall be finished to a diameter between 0.625 in. (15.9 mm) and 0.875 in. (22.2 mm), with preference given to lower diameters.

The microstructure shall be uniform through the thickness, with an ASTM grain size No. 7 or finer, determined in accordance with ASTM E112.

The bar hardness shall not exceed HRB = 100, HV = 252, HRC = 24, or HB = 245 (depending on the hardness scale used).

In order to avoid twist and bow, the bars shall be either vertically hung during the heat treatment (vertical heat treatment - preferred method), or machine straightened.

The amount ordered shall be between 1,200 lbs. – 10,000 lbs., with preference given to quantities of 3,500 lbs. and above.

The bars shall be shipped in lengths of no more than 6 feet, and shall be securely packaged in boxes weighing no more than 2,500 lbs. each.

Appendix C. Certificate of Tests for 4340 steel Heat J4905

CARPENTER TECHNOLOGY

Certification ID: 000010071653_0002

CARPENTER TECHNOLOGY CORP.
LATROBE OPERATIONS (PA)
2626 LIGONIER STREET
LATROBE PA 15650

A SSA 66 C=.40-.43%
EXC: 299-947-055 REV. AH
JAN 06 2023

Certificate of Tests

Ship To

Cert To

Sales Order Information	
Sales Order/Item:	54959/10
Customer PO/Item:	29-362390/000001

Delivery Information	
Delivery:	80208383
Picked Date:	12/13/2022
Quantity Shipped:	6,621 LB

Production Information	
Production Order:	10071653
Heat Number:	J4905
Ingot(s) Shipped*:	2

The recording of false, fictitious or fraudulent statements or entries on this document may be punished as a felony under federal statues including federal law, Title 18, Chapter 47.
The values and other technical data represent the results of analyses and tests made on samples collected from the total lot. Original data records can be traced by reference to the Carpenter order number.
During the manufacturing process, this material has not come in direct contact with Mercury or any of its compounds. The material has not come in contact with any radioactive sources, Cobalt 60, Radium or Alpha-Source nor devices employing a single boundary of containment. Material is also weld free.

Material has been melted in USA or qualifying country to DFARS requirements 252.225-7014 with alternate 1 for qualifying country 225.872.1, superseded by DFARS requirements DFARS 252.225-7008 and 252.225-7009.

This order was manufactured in accordance with Carpenter Specialty Alloys Operations Quality Program Manual, Revision 38 dated 08/21/2022.
Carpenter Technology Corporation is registered to Quality Management System Standards: ISO 9001, AS9120 and AS9100.
This certificate of test is Type 3.1 prepared in accordance with EN 10204 (DIN 50049).
We certify this material to have been manufactured, inspected, and tested; and found the results to conform to all drawing and/or specification requirements and order requirements as applicable.
Carpenter Technology third party accreditation certificates are available on the company website: https://www.carpentertechnology.com/quality-certifications

Decision Rule: Unless otherwise specified in a customer/industry specification, Carpenter Technology Corporation will determine acceptability of any test result by comparison of the result with the specification limits, without any additional consideration of the measurement uncertainty. When requested, Carpenter Technology Corporation will provide uncertainty budgets for any test result that is not addressed by the industry standard. When a Decision Rule is defined in a customer/industry specification it will supersede the Corporate Decision Rule.

*Ingot(s) Shipped represents the ingots that were shipped on the specified delivery. The material produced and certified may include additional ingots that were not shipped.

J4905-2

Page 1 of 7

CARPENTER TECHNOLOGY

Certificate ID : 000010071653_0002
Production Order : 10071653
Heat Number : J4905

Certificate of Tests

PRODUCT DESCRIPTION :
4340
NORMALIZED, TEMPERED, PEELED, POLISHED

SPECIFICATIONS :
AMS 2300 Rev M 05/01/2020,
AMS 6415 REV U 12/01/2016,
AMS 6414 Rev M 12/01/2016,
299-947-055 REV AH 10/29/2016 TYPE I Exception Letter 07/16/2021 PENDING,
PRATT & WHITNEY MCL F-17 REV D 10/17/2019,
SS9702 REV 4 07/26/2013 Gr 2 & 3 - Forg Stk,
EMS 4.1 REV E-1 05/17/2002,
PRATT & WHITNEY MCL F-14 REV D 06/28/2017,
S-SPEC-1 (S-1000) 04/01/2021,
S-SPEC-35 (S-400) 02/28/2021,
PRATT & WHITNEY ASQR-01 Rev 11 08/31/2018,
BMS 7-28 REV G 09/14/1987,
PRATT & WHITNEY PWA-S-6415 REV E 12/13/2011 NON-ROTOR,
PRATT & WHITNEY PWA-S-6414 REV B 11/03/2011 NON-ROTOR,
PRATT & WHITNEY PWA 300 REV BT 07/30/2021 PWA-S-6414/6415 (NR)
AMS 2301 Rev L 05/01/2020
AS6174 REV A 07/01/2014
ISO 17025 3RD ED
PRATT & WHITNEY MCL F-23 REV G 04/26/2019
PRATT & WHITNEY PWA 300 REV BT 07/30/2021 PWA-S-6415 NON-ROTOR
PRATT & WHITNEY PWA 301 REV AY 08/06/2015
PRATT & WHITNEY PWA-S-6414 REV B 11/03/2011 NON-ROTOR

SIZE :
0.625 (15.875 MM) ROUND BAR INGOT# 2

CHEMISTRY

Chemical Composition

Ingot Average Location	C	SI	MN	S	P	CR
Ingot 2	0.41	0.31	0.78	<0.001	0.004	0.86

Location	NI	MO	CU
Ingot 2	1.94	0.26	0.07

MACROSTRUCTURE

Macrostructure (DI)
Method: ASTM A604/A604M & ASTM E340
TESTED AT 0.7950 RND

Location	PHOTO	RESULT
2D	ASTM A-604 (1)	A
	ASTM A-604 (2)	A
	ASTM A-604 (3)	A

CARPENTER TECHNOLOGY

Certificate ID : 000010071653_0002
Production Order : 10071653
Heat Number : J4905

Certificate of Tests

	ASTM A-604 (4)	A
2E	ASTM A-604 (1)	A
	ASTM A-604 (2)	A
	ASTM A-604 (3)	A
	ASTM A-604 (4)	A
2F	ASTM A-604 (1)	A
	ASTM A-604 (2)	A
	ASTM A-604 (3)	A
	ASTM A-604 (4)	A
2G	ASTM A-604 (1)	A
	ASTM A-604 (2)	A
	ASTM A-604 (3)	A
	ASTM A-604 (4)	A

This test was performed at Carpenter Technology Corporation - Reading Operations, 101 West Bern Street, Reading, PA 19601

Macrostructure (DI)
Method: ASTM A604/A604M & ASTM E340
TESTED AT 5.0001 X 5.0001 RCS

Location	PHOTO	RESULT
2A1	ASTM A-604 (1)	A
	ASTM A-604 (2)	A
	ASTM A-604 (3)	A
	ASTM A-604 (4)	A
2X1	ASTM A-604 (1)	A
	ASTM A-604 (2)	A
	ASTM A-604 (3)	A
	ASTM A-604 (4)	A

This test was performed at Carpenter Technology Corporation - Athens Operations, 22110 Thomas L Hammons Road, Tanner, AL 35671.

Macrostructure (DI)
Method: ASTM E340 & ASTM E381
TESTED AT 0.7950 RND

Location	PHOTO	RESULT
2H	E-381 (S)	1
	E-381 (R)	1
	E-381 (C)	1
2I	E-381 (S)	1
	E-381 (R)	1
	E-381 (C)	1
2J	E-381 (S)	1
	E-381 (R)	1
	E-381 (C)	1
2K	E-381 (S)	1

CARPENTER TECHNOLOGY

Certificate ID : 000010071653_0002
Production Order : 10071653
Heat Number : J4905

Certificate of Tests

	E-381 (R)	1
	E-381 (C)	1

This test was performed at Carpenter Technology Corporation - Reading Operations, 101 West Bern Street, Reading, PA 19601

Macrostructure (DI)
Method: ASTM E340 & ASTM E381
TESTED AT 5.0001 X 5.0001 RCS

Location	PHOTO	RESULT
2A1	E-381 (S)	1
	E-381 (R)	1
	E-381 (C)	1
2X1	E-381 (S)	1
	E-381 (R)	1
	E-381 (C)	1

This test was performed at Carpenter Technology Corporation - Athens Operations, 22110 Thomas L Hammons Road, Tanner, AL 35671.

MICROSTRUCTURE
Micro Decarburization
Decarburization per ASTM E1077: FREE
Test pieces heat treated to 1,900 °F, 1 MIN, CMS, CMS / 1,100 °F, 2 MIN, CMS, AC prior to testing

Micro Inclusion JK
Method: ASTM E45 (Method A)

Location	A (T)	A (H)	B (T)	B (H)	C (T)	C (H)	D (T)	D (H)
2A1	0	0	0	0	0	0	0	0
2X1	0	0	0	0	0	0	0	0

The worst field and total rateable fields frequency requirements were found to be within applicable specification limits.

Micro Chem Band

Location	PHOTO	RESULT
T8	Microhardness (RC Spread)	0.7

Test pieces heat treated to 1,500 °F, 30 MIN, OT prior to testing

Micro Inclusion JK
Method: ASTM E45 (Method D)

Location	A (T)	A (H)	B (T)	B (H)	C (T)	C (H)	D (T)	D (H)
2A1	0	0	0	0	0	0	0	0
2X1	0	0	0	0	0	0	0	0

The worst field and total rateable fields frequency requirements were found to be within applicable specification limits.

CARPENTER TECHNOLOGY

Certificate ID : 000010071653_0002
Production Order : 10071653
Heat Number : J4905

Certificate of Tests

MECHANICAL PROPERTIES

Jominy Hardenability

Method: ASTM A255

Location	16THS	HRC
1X1	1	59.9
1X1	2	59.6
1X1	3	59.4
1X1	4	58.5
1X1	5	58.6
1X1	6	58.1
1X1	7	57.6
1X1	8	57.2
1X1	9	57.2
1X1	10	56.7
1X1	11	56.5
1X1	12	56.1
1X1	14	56.2
1X1	16	56.3
1X1	18	56.2
1X1	20	55.9
1X1	24	55.8
1X1	28	55.9
1X1	32	55.6

Test pieces heat treated to 1,600 °F, 1 H, AC / 1,550 °F, 30 MIN, WT prior to testing

Hardness

Method: ASTM E18 & ASTM A370

Location	RADIAL LOC.	RESULT(S) HRC
2B	MID-RADIUS	23.9
2C	MID-RADIUS	21.9

CAPABILITY MICROSTRUCTURE

Cap Micro Grain Size

Method: ASTM E112

Location	GRAIN SIZE
T9	7.5

Test pieces heat treated to 1,575 °F, 1 H, WT prior to testing

Cap Micro Grain Size

Method: ASTM E112

Location	GRAIN SIZE
2M	8

Test pieces heat treated to 1,575 °F, 1 H, WT prior to testing

CARPENTER TECHNOLOGY

Certificate ID : 000010071653_0002
Production Order : 10071653
Heat Number : J4905

Certificate of Tests

CAPABILITY MECHANICAL PROPERTIES

Cap Tension

Method: ASTM E8/E8M & ASTM A370
TESTED AT 5.0001 X 5.0001 RCS
ORIENTATION: TRANSVERSE

Location	RADIAL LOC.	UTS (KSI)	YS (0.2)KSI	ELONG (4D)%	RA %
2A1	CENTER	269	224	10	40
2A1	CENTER	269	223	11	42
2X1	CENTER	268	222	12	46
2X1	CENTER	268	222	12	46

Test pieces heat treated to 1,650 °F, 1 H, AC / 1,500 °F, 1 H, OT / 475 °F, 2 H, AC / 475 °F, 2 H, AC prior to testing
A .505" Rd. tensile specimen was used.

Cap Tension

Method: ASTM E8/E8M & ASTM A370
TESTED AT 5.0001 X 5.0001 RCS
ORIENTATION: TRANSVERSE

Location	RADIAL LOC.	UTS (KSI)	YS (0.2)KSI	ELONG (4D)%	RA %
2A1	MID-RADIUS	269	222	11	39
2A1	MID-RADIUS	269	222	11	44
2X1	MID-RADIUS	267	221	11	44
2X1	MID-RADIUS	266	220	12	47

Test pieces heat treated to 1,650 °F, 1 H, AC / 1,500 °F, 1 H, OT / 475 °F, 2 H, AC / 475 °F, 2 H, AC prior to testing
A .505" Rd. tensile specimen was used.

MAGNETIC PARTICLE

Magnetic Particle

Method: AMS 2300

Location	F	S
2A1	0	0
2X1	0	0

This test was performed at CARPENTER TECHNOLOGY CORP- READING, WEST BERN ST, READING, PA, 19601 Report No. 2204180218

CERTIFICATION STATEMENT

All bars grade verified by Spectrotest.

Material was produced, controlled and tested in accordance PWA MCL LCS F-17 including PWA 300 and MCL Manual Sections F-14, F-22, and F-23 (latest revisions).

GEAG SUPPLIER CODE - 21100/CARPENTER, T9406/ATHENS, 51904/LATROBE

Carpenter Technology Corporation supply chain controls take into account Dodd Frank Act requirements regarding conflict minerals

CARPENTER TECHNOLOGY

Certificate ID : 000010071653_0002
Production Order : 10071653
Heat Number : J4905

Certificate of Tests

AMS 6414M (SUPERSEDES MIL-S-8844D NOTICE 1) AMS 6415U (REPLACES AMS-S-5000A/MIL-S-5000E) EXCEPT VAR

This material has been ARC-VAR melted

Material tested in accordance with AMS 2300 to satisfy the requirements of AMS 2301

Country of origin (Manufacturing & Melting): USA

Testing methods for chemical analysis tested at Latrobe Specialty Metals are as follows: C & S = Combustion N, O & H = Fusion Si, Mn, W, Cr, V, Ni, Mo, Co, Cu, Ti >0.1%, Cb, Ta, Fe, Al >1 %, Zr = X-ray or OES P, Al <1%, B, Ti <0.1 %, Pb, Mg, Ca, As = OES Sn per procedure X-ray or OES. Other testing methods not listed above have been conducted per certified material specification(s).

Unless otherwise stated, the tests were performed to the latest revision of the standards listed below: 1) Bend Test - ASTM E290, 2) Charpy Impact - ASTM E23, 3) Coefficient of Linear Thermal Expansion - ASTM E228, 4) Fracture Toughness - ASTM E399, 5) Brinell Hardness - ASTM E10, 6) Rockwell Hardness - ASTM E18, 7) Micro Vickers Hardness - ASTM E92, 8) Knoop Hardness - ASTM E92, 9) Macro Vickers Hardness - ASTM E92, 10) Stress Rupture / Creep Rupture - ASTM E139, 11) Stress Rupture (Combination) - ASTM E292, 12) Room Temperature Tensile - ASTM E8, 13) Elevated Room Temperature Tensile - ASTM E21, 14) Decarburization - ASTM E1077 15) Delta Ferrite - AMS 2315, 16) Grain Size - ASTM E112, 17) Inclusion Content/Microcleanliness - ASTM E45, 18) Intergranular Attach - ASTM A262, 19) Intergranular Corrosion - ASTM A262, 20) Macro Etch & Testing - ASTM A604/E381, 21) Pitting Corrosion - ASTM A923, 22) Crevice Corrosion -ASTM G48, 23) Hardness Conversions - ASTM E140, 24) XRF - ASTM E572/E1085/E2465, 25) OES - ASTM E415/E1086, 26) COM - ASTM E1019, 27) FUS - ASTM E1019, 28) MS - Carpenter Methods 206.8500/206.8530

Breanna Lickenfelt

12/07/2022

BREANNA LICKENFELT
ADMINISTRATOR II - QUALITY
Carpenter Technology Corporation

Appendix D. Individual hardness measurements and Charpy results for Heat J4905

Machine	KV (J)	Hardness
SI	19.05	46.05
SI	19.91	45.20
SI	20.42	46.30
SI	19.98	46.00
SI	19.55	46.20
SI	19.41	46.40
SI	19.91	46.20
SI	20.27	46.10
SI	20.12	46.15
SI	19.76	45.80
SI	19.26	
SI	19.70	
SI	19.34	
SI	19.55	
SI	19.55	
SI	19.26	
SI	19.76	
SI	20.06	
SI	20.27	
SI	19.55	
SI	19.26	
SI	19.34	
SI	19.84	
SI	19.11	
TO	19.84	46.15
TO	19.58	46.30
TO	19.67	46.15
TO	19.49	46.35
TO	20.01	45.20
TO	19.41	46.10
TO	19.49	46.10
TO	19.41	46.25
TO	19.32	46.30
TO	19.84	46.45
TO	20.01	
TO	19.49	
TO	19.75	
TO	19.58	
TO	19.49	
TO	19.41	
TO	18.98	
TO	20.01	
TO	19.67	
TO	19.41	
TO	19.41	
TO	20.01	
TO	19.75	
TO	19.49	
TO	20.27	
TK	17.80	46.25
TK	18.30	46.40
TK	18.71	46.50
TK	18.30	46.25
TK	18.50	46.15
TK	17.50	46.35
TK	18.30	46.25
TK	18.91	46.25
TK	19.61	46.30
TK	18.30	46.15
TK	17.40	
TK	17.90	
TK	18.40	
TK	18.10	
TK	18.20	
TK	18.71	
TK	17.90	
TK	18.50	
TK	18.40	
TK	18.61	
TK	17.80	
TK	19.01	
TK	17.80	
TK	18.10	

Appendix E. Certificate of Tests for 4340 steel Heat J4906

CARPENTER TECHNOLOGY

Certificate ID : 000010076698_0002
Production Order : 10076698
Heat Number : J4906

Certificate of Tests

PRODUCT DESCRIPTION :
4340 NORMALIZED, TEMPERED, PEELED, POLISHED

SPECIFICATIONS :
AMS 2300 Rev M 05/01/2020,
AMS6415 REV V 11/2022*
AMS 6414 REV N 03/2023 (SUPERSEDES MIL-S-8844D NOTICE 1)*
299-947-055 REV AH 10/29/2016 TYPE I Exception Letter 07/16/2021 PENDING,
SS9702 REV 4 07/26/2013 Gr 2 & 3 - Forg Stk,
EMS 4.1 REV E-1 05/17/2002,
S-SPEC-1 (S-1000) 04/01/2021,
S-SPEC-35 (S-400) 02/28/2021,
BMS 7-28 REV G 09/14/1987,
*
*
*
*
*
AMS 2301 Rev L 05/01/2020

SIZE :
0.625 (15.875 MM) ROUND BAR INGOT #1

CHEMISTRY
Chemical Composition
Ingot Average

Location	C	SI	MN	S	P	CR
Ingot 1	0.42	0.30	0.76	0.001	0.006	0.84
Location	NI	MO	CU			
Ingot 1	1.92	0.26	0.07			

MACROSTRUCTURE
Macrostructure (DI)
Method: ASTM E340 & ASTM E381
TESTED AT 5.0001 X 5.0001 RCS

Location	PHOTO	RESULT
1A1	E-381 (S)	1
	E-381 (R)	1
	E-381 (C)	1
1X1	E-381 (S)	1
	E-381 (R)	1
	E-381 (C)	1

This test was performed at Carpenter Technology Corporation - Athens Operations, 22110 Thomas L Hammons Road, Tanner, AL 35671.

Page 2 of 6

The certification is made to the customer printed on the form. Carpenter neither makes, nor assumes responsibility for any representation or certification to other parties.(Form E2-366)

CARPENTER TECHNOLOGY

Certificate ID : 000010076698_0002
Production Order : 10076698
Heat Number : J4906

Certificate of Tests

Macrostructure (DI)
Method: ASTM A604/A604M & ASTM E340
TESTED AT 5.0001 X 5.0001 RCS

Location	PHOTO	RESULT
1A1	ASTM A-604 (1)	A
	ASTM A-604 (2)	A
	ASTM A-604 (3)	A
	ASTM A-604 (4)	A
1X1	ASTM A-604 (1)	A
	ASTM A-604 (2)	A
	ASTM A-604 (3)	A
	ASTM A-604 (4)	A

This test was performed at Carpenter Technology Corporation - Athens Operations, 22110 Thomas L Hammons Road, Tanner, AL 35671.

Macrostructure (DI)
Method: ASTM E340 & ASTM E381
TESTED AT 0.7950 RND

Location	PHOTO	RESULT
ALL	E-381 (S)	1
	E-381 (R)	1
	E-381 (C)	2

This test was performed at Carpenter Technology Corporation - Reading Operations, 101 West Bern Street, Reading, PA 19601

Macrostructure (DI)
Method: ASTM A604/A604M & ASTM E340
TESTED AT 0.7950 RND

Location	PHOTO	RESULT
ALL	ASTM A-604 (1)	A
	ASTM A-604 (2)	A
	ASTM A-604 (3)	B
	ASTM A-604 (4)	B

This test was performed at Carpenter Technology Corporation - Reading Operations, 101 West Bern Street, Reading, PA 19601

MICROSTRUCTURE
Micro Inclusion JK
Method: ASTM E45 (Method D)

Location	A (T)	A (H)	B (T)	B (H)	C (T)	C (H)	D (T)	D (H)
1A1	0	0	0	0	0	0	0	0
1X1	0	0	0	0	0	0	0	0

The worst field and total rateable fields frequency requirements were found to be within applicable specification limits.

CARPENTER TECHNOLOGY

Certificate ID : 000010076698_0002
Production Order : 10076698
Heat Number : J4906

Certificate of Tests

Micro Chem Band

Location	PHOTO	RESULT
DP	Microhardness (RC Spread)	2.2

Test pieces heat treated to 1,500 °F, 30 MIN, OT prior to testing

Micro Decarburization

Decarburization per ASTM E1077: FREE
Test pieces heat treated to 1,550 °F, 30 MIN, OT prior to testing

Micro Grain Size

Method: ASTM E112

Location	GRAIN SIZE
I6	8.0

Test pieces heat treated to 1,575 °F, 1 H, WT prior to testing

Micro Inclusion JK

Method: ASTM E45 (Method A)

Location	A (T)	A (H)	B (T)	B (H)	C (T)	C (H)	D (T)	D (H)
1A1	0	0	0	0	0	0	0	0
1X1	0	0	0	0	0	0	0	0

MECHANICAL PROPERTIES

Jominy Hardenability

Method: ASTM A255

Location	16THS	HRC
1X1	6	58.1
1X1	11	56.5
1X1	12	57.0
1X1	20	56.5
1X1	32	55.7

Test pieces heat treated to 1,600 °F, 1 H, AC / 1,550 °F, 30 MIN, WT prior to testing

Hardness

Method: ASTM E18 & ASTM A370

Location	RADIAL LOC.	RESULT(S) HRC
I2	MID-RADIUS	21.7
I3	MID-RADIUS	20.3

CAPABILITY MECHANICAL PROPERTIES

Cap Tension

Method: ASTM E8/E8M & ASTM A370
TESTED AT 5.0001 X 5.0001 RCS
ORIENTATION: TRANSVERSE

Location	RADIAL LOC.	UTS (KSI)	YS (0.2)KSI	ELONG (4D)%	RA %
1A1	CENTER	266	221	10	41
1A1	CENTER	268	221	10	43

CARPENTER TECHNOLOGY

Certificate ID : 000010076698_0002
Production Order : 10076698
Heat Number : J4906

Certificate of Tests

1X1	CENTER	270	224	11	43
1X1	CENTER	270	224	11	43

Test pieces heat treated to 1,650 °F, 1 H, AC / 1,500 °F, 1 H, OT / 475 °F, 2 H, AC / 475 °F, 2 H, AC prior to testing
A .505" Rd. tensile specimen was used.

Cap Tension
Method: ASTM E8/E8M & ASTM A370
TESTED AT 5.0001 X 5.0001 RCS
ORIENTATION: TRANSVERSE

Location	RADIAL LOC.	UTS (KSI)	YS (0.2)KSI	ELONG (4D)%	RA %
1A1	MID-RADIUS	269	222	11	45
1A1	MID-RADIUS	270	223	12	45
1X1	MID-RADIUS	270	224	11	43
1X1	MID-RADIUS	269	223	11	44

Test pieces heat treated to 1,650 °F, 1 H, AC / 1,500 °F, 1 H, OT / 475 °F, 2 H, AC / 475 °F, 2 H, AC prior to testing
A .505" Rd. tensile specimen was used.

MAGNETIC PARTICLE

Magnetic Particle
Method: AMS 2300

Location	F	S
1X1	0	0
1A1	0	0

This test was performed at CARPENTER TECHNOLOGY CORP- READING, WEST BERN ST, READING, PA, 19601 Report No. 2203310004

CERTIFICATION STATEMENT

3:1 minimum reduction ratio from ingot to final product

Carpenter Technology Corporation supply chain controls take into account Dodd Frank Act requirements regarding conflict minerals

All bars grade verified by Spectrotest.

*AMS 6414 REV N 03/2023 (SUPERSEDES MIL-S-8844D NOTICE 1) AMS6415 REV V 11/2022

Process qualification in accordance with 4.2.3 and 4.2.3.1 of AMS 2300 has been completed

MATERIAL CONFORMS TO THE REQUIREMENTS OF AMS 6414.

GEAG SUPPLIER CODE - 21100/CARPENTER, T9406/ATHENS, 51904/LATROBE

This material has been ARC-VAR melted

CARPENTER TECHNOLOGY

Certificate ID : 000010076698_0002
Production Order : 10076698
Heat Number : J4906

Certificate of Tests

Subcritically Annealed

Material tested in accordance with AMS 2300 to satisfy the requirements of AMS 2301

Carpenter Technology has complied with all producer requirements of AS6279.

Country of origin (Manufacturing & Melting): USA

*Original certificate issued 11/18/2022; amended per customer request.

Testing methods for chemical analysis tested at Latrobe Specialty Metals are as follows: C & S = Combustion N, O & H = Fusion Si, Mn, W, Cr, V, Ni, Mo, Co, Cu, Ti >0.1%, Cb, Ta, Fe, Al >1 %, Zr = X-ray or OES P, Al <1%, B, Ti <0.1 %, Pb, Mg, Ca, As = OES Sn per procedure X-ray or OES. Other testing methods not listed above have been conducted per certified material specification(s).

Unless otherwise stated, the tests were performed to the latest revision of the standards listed below: 1) Bend Test - ASTM E290, 2) Charpy Impact - ASTM E23, 3) Coefficient of Linear Thermal Expansion - ASTM E228, 4) Fracture Toughness - ASTM E399, 5) Brinell Hardness - ASTM E10, 6) Rockwell Hardness - ASTM E18, 7) Micro Vickers Hardness - ASTM E92, 8) Knoop Hardness - ASTM E92, 9) Macro Vickers Hardness - ASTM E92, 10) Stress Rupture / Creep Rupture - ASTM E139, 11) Stress Rupture (Combination) - ASTM E292, 12) Room Temperature Tensile - ASTM E8, 13) Elevated Room Temperature Tensile - ASTM E21, 14) Decarburization - ASTM E1077 15) Delta Ferrite - AMS 2315, 16) Grain Size - ASTM E112, 17) Inclusion Content/Microcleanliness - ASTM E45, 18) Intergranular Attach - ASTM A262, 19) Intergranular Corrosion - ASTM A262, 20) Macro Etch & Testing - ASTM A604/E381, 21) Pitting Corrosion - ASTM A923, 22) Crevice Corrosion -ASTM G48, 23) Hardness Conversions - ASTM E140, 24) XRF - ASTM E572/E1085/E2465, 25) OES - ASTM E415/E1086, 26) COM - ASTM E1019, 27) FUS - ASTM E1019, 28) MS - Carpenter Methods 206.8500/206.8530

Breanna Lickenfelt

11/09/2023

BREANNA LICKENFELT
ADMINISTRATOR II - QUALITY
Carpenter Technology Corporation

Appendix F. Certificate of Tests for 4340 steel Heat J4943

CARPENTER TECHNOLOGY

Certification ID: 000010086453_0002

CARPENTER TECHNOLOGY CORP.
LATROBE OPERATIONS (PA)
2626 LIGONIER STREET
LATROBE PA 15650

Certificate of Tests

Sales Order Information	
Sales Order/Item:	60139/10
Customer PO/Item:	27-159975/000001

Delivery Information	
Delivery:	80237153
Picked Date:	03/10/2023
Quantity Shipped:	582 LB

Production Information	
Production Order:	10086453
Heat Number:	J4943
Ingot(s) Shipped*:	3

The recording of false, fictitious or fraudulent statements or entries on this document may be punished as a felony under federal statues including federal law, Title 18, Chapter 47.
The values and other technical data represent the results of analyses and tests made on samples collected from the total lot. Original data records can be traced by reference to the Carpenter order number.
During the manufacturing process, this material has not come in direct contact with Mercury or any of its compounds. The material has not come in contact with any radioactive sources, Cobalt 60, Radium or Alpha-Source nor devices employing a single boundary of containment. Material is also weld free.

Material has been melted in USA or qualifying country to DFARS requirements 252.225-7014 with alternate 1 for qualifying country 225.872.1, superseded by DFARS requirements DFARS 252.225-7008 and 252.225-7009.

This order was manufactured in accordance with Carpenter Specialty Alloys Operations Quality Program Manual, Revision 38 dated 08/21/2022.
Carpenter Technology Corporation is registered to Quality Management System Standards: ISO 9001, AS9120 and AS9100.
This certificate of test is Type 3.1 prepared in accordance with EN 10204 (DIN 50049).
We certify this material to have been manufactured, inspected, and tested; and found the results to conform to all drawing and/or specification requirements and order requirements as applicable.
Carpenter Technology third party accreditation certificates are available on the company website: https://www.carpentertechnology.com/quality-certifications

Decision Rule: Unless otherwise specified in a customer/industry specification, Carpenter Technology Corporation will determine acceptability of any test result by comparison of the result with the specification limits, without any additional consideration of the measurement uncertainty. When requested, Carpenter Technology Corporation will provide uncertainty budgets for any test result that is not addressed by the industry standard. When a Decision Rule is defined in a customer/industry specification it will supersede the Corporate Decision Rule.

*Ingot(s) Shipped represents the ingots that were shipped on the specified delivery. The material produced and certified may include additional ingots that were not shipped.

CARPENTER TECHNOLOGY

Certificate ID : 000010086453_0002
Production Order : 10086453
Heat Number : J4943

Certificate of Tests

PRODUCT DESCRIPTION :
4340
NORMALIZED, TEMPERED, PEELED, POLISHED

SPECIFICATIONS :
299-947-055 REV AH 10/29/2016 TYPE I Exception Letter 07/16/2021 PENDING
AMS 2300 Rev M 05/01/2020
AMS 2301 Rev L 05/01/2020
AMS 6414 Rev N 03/2023*
AMS 6415 REV V 11/01/2022
BMS 7-28 REV G 09/14/1987
EMS 4.1 REV E-1 05/17/2002
SS9702 REV 4 07/26/2013 Gr 2 & 3 - Forg Stk
S-SPEC-1 (S-1000) 04/01/2021
S-SPEC-35 (S-400) 02/28/2021

SIZE :
0.625 (15.875 MM) ROUND BAR
INGOT #3

CHEMISTRY (WT%)

Chemical Composition
Ingot Average

Location	C	SI	MN	S	P	CR
Ingot 3	0.42	0.29	0.76	<0.001	0.005	0.86
Location	NI	MO	CU			
Ingot 3	1.92	0.27	0.07			

MACROSTRUCTURE

Macrostructure (DI)
Method: ASTM A604/A604M & ASTM E340
TESTED AT 5.0001 X 5.0001 RCS

Location	PHOTO	RESULT
3A1	ASTM A-604 (1)	A
	ASTM A-604 (2)	A
	ASTM A-604 (3)	A
	ASTM A-604 (4)	A
3X1	ASTM A-604 (1)	A
	ASTM A-604 (2)	A
	ASTM A-604 (3)	A
	ASTM A-604 (4)	A

This test was performed at Carpenter Technology Corporation - Athens Operations, 22110 Thomas L Hammons Road, Tanner, AL 35671.

CARPENTER TECHNOLOGY

Certificate ID : 000010086453_0002
Production Order : 10086453
Heat Number : J4943

Certificate of Tests

Macrostructure (DI)
Method: ASTM E340 & ASTM E381
TESTED AT 5.0001 X 5.0001 RCS

Location	PHOTO	RESULT
3A1	E-381 (S)	1
	E-381 (R)	1
	E-381 (C)	1
3X1	E-381 (S)	1
	E-381 (R)	1
	E-381 (C)	1

This test was performed at Carpenter Technology Corporation - Athens Operations, 22110 Thomas L Hammons Road, Tanner, AL 35671.

Macrostructure (DI)
Method: ASTM A604/A604M & ASTM E340
TESTED AT 0.7950 RND

Location	PHOTO	RESULT
3U	ASTM A-604 (1)	A
	ASTM A-604 (2)	A
	ASTM A-604 (3)	A
	ASTM A-604 (4)	A
3V	ASTM A-604 (1)	A
	ASTM A-604 (2)	A
	ASTM A-604 (3)	A
	ASTM A-604 (4)	A
3W	ASTM A-604 (1)	A
	ASTM A-604 (2)	A
	ASTM A-604 (3)	A
	ASTM A-604 (4)	A
3X	ASTM A-604 (1)	A
	ASTM A-604 (2)	A
	ASTM A-604 (3)	A
	ASTM A-604 (4)	A

This test was performed at Carpenter Technology Corporation - Reading Operations, 101 West Bern Street, Reading, PA 19601

Macrostructure (DI)
Method: ASTM E340 & ASTM E381
TESTED AT 0.7950 RND

Location	PHOTO	RESULT
3Q	E-381 (S)	1
	E-381 (R)	1
	E-381 (C)	1
3R	E-381 (S)	1
	E-381 (R)	1
	E-381 (C)	1

CARPENTER TECHNOLOGY

Certificate ID : 000010086453_0002
Production Order : 10086453
Heat Number : J4943

Certificate of Tests

3S	E-381 (S)	1
	E-381 (R)	1
	E-381 (C)	1
3T	E-381 (S)	1
	E-381 (R)	1
	E-381 (C)	1

This test was performed at Carpenter Technology Corporation - Reading Operations, 101 West Bern Street, Reading, PA 19601

MICROSTRUCTURE

Micro Decarburization

Decarburization per ASTM E1077: FREE
Test pieces heat treated to 1,550°F, 30 MIN, OT prior to testing

Micro Inclusion JK

Method: ASTM E45 (Method A)

Location	A (T)	A (H)	B (T)	B (H)	C (T)	C (H)	D (T)	D (H)
3A1	0	0	0	0	0	0	0	0
3X1	0	0	0	0	0	0	0	0

The worst field and total rateable fields frequency requirements were found to be within applicable specification limits.

Micro Inclusion JK

Method: ASTM E45 (Method D)

Location	A (T)	A (H)	B (T)	B (H)	C (T)	C (H)	D (T)	D (H)
3A1	0	0	0	0	0	0	0	0
3X1	0	0	0	0	0	0	0	0

The worst field and total rateable fields frequency requirements were found to be within applicable specification limits.

Micro Chem Band

Location	PHOTO	RESULT
YJ	Microhardness (RC Spread)	1.9

Test pieces heat treated to 1,500°F, 30 MIN, OT prior to testing

Micro Grain Size

Method: ASTM E112

Location	GRAIN SIZE
3P	8.0

Test pieces heat treated to 1,575°F, 1 H, WT prior to testing

CARPENTER TECHNOLOGY

Certificate ID : 000010086453_0002
Production Order : 10086453
Heat Number : J4943

Certificate of Tests

MECHANICAL PROPERTIES

Hardness

Method: ASTM E18 & ASTM A370

Location	RADIAL LOC.	RESULT(S) HRC
3L	MID-RADIUS	22.1
3M	MID-RADIUS	20.6

Jominy Hardenability

Method: ASTM A255

Location	16THS	HRC
1X1	1	59.3
1X1	2	59.0
1X1	3	58.6
1X1	4	57.5
1X1	5	57.7
1X1	6	57.4
1X1	7	57.9
1X1	8	57.7
1X1	9	57.0
1X1	10	57.9
1X1	11	57.5
1X1	12	56.6
1X1	14	56.2
1X1	16	55.7
1X1	18	56.3
1X1	20	56.5
1X1	24	56.1
1X1	28	55.7
1X1	32	55.4

Test pieces heat treated to 1,600°F, 1 H, AC / 1,550°F, 30 MIN, WT prior to testing

CAPABILITY MECHANICAL PROPERTIES

Cap Tension

Method: ASTM E8/E8M & ASTM A370

TESTED AT 5.0001 X 5.0001 RCS

ORIENTATION:		TRANSVERSE			
Location	RADIAL LOC.	UTS(KSI)	YS(0.2)KSI	ELONG(4D)%	RA%
3A1	CENTER	267	223	13	45
3A1	CENTER	268	222	12	44
3X1	CENTER	269	223	13	44
3X1	CENTER	269	221	12	44
3A1	MID-RADIUS	269	224	11	45
3A1	MID-RADIUS	269	222	11	46

CARPENTER TECHNOLOGY

Certificate ID : 000010086453_0002
Production Order : 10086453
Heat Number : J4943

Certificate of Tests

3X1	MID-RADIUS	268	224	12	46
3X1	MID-RADIUS	267	224	11	46

Test pieces heat treated to 1,650°F, 1 H, AC / 1,500°F, 1 H, OT / 475°F, 2 H, AC / 475°F, 2 H, AC prior to testing
A .505" Rd. tensile specimen was used.

MAGNETIC PARTICLE

Magnetic Particle
Method: AMS 2300

Location	F	S
3A1	0	0
3X1	0	0

This test was performed at CARPENTER TECHNOLOGY CORP- READING, WEST BERN ST, READING, PA, 19601
Report No. 2204260099

CERTIFICATION STATEMENT

AMS 6414M (Supersedes MIL-S-8844D Notice 1), AMS 6415U (Replaces AMS-S-5000A/MIL-S-5000E) Except VAR.

MATERIAL CONFORMS TO THE REQUIREMENTS OF AMS 6414.

Material tested in accordance with AMS 2300 to satisfy the requirements of AMS 2301.

Process qualification in accordance with 4.2.3 and 4.2.3.1 of AMS 2300 has been completed.

3:1 minimum reduction ratio from ingot to final product.

All bars grade verified by Spectrotest.

Subcritically Annealed

Carpenter Technology Corporation supply chain controls take into account Dodd Frank Act requirements regarding conflict minerals.

GEAG SUPPLIER CODE - 21100/CARPENTER, T9406/ATHENS, 51904/LATROBE

This material has been ARC-VAR melted.

Carpenter Technology has complied with all producer requirements of AS6279.

Country of origin (Manufacturing & Melting): USA

*Original certificate issued 03/10/2023; amended per customer request.

CARPENTER TECHNOLOGY

Certificate ID : 000010086453_0002
Production Order : 10086453
Heat Number : J4943

Certificate of Tests

Testing methods for chemical analysis tested at Latrobe Specialty Metals are as follows: C & S = Combustion N, O & H = Fusion Si, Mn, W, Cr, V, Ni, Mo, Co, Cu, Ti >0.1%, Cb, Ta, Fe, Al >1 %, Zr = X-ray or OES P, Al <1%, B, Ti <0.1 %, Pb, Mg, Ca, As = OES Sn per procedure X-ray or OES. Other testing methods not listed above have been conducted per certified material specification(s).

Unless otherwise stated, the tests were performed to the latest revision of the standards listed below: 1) Bend Test - ASTM E290, 2) Charpy Impact - ASTM E23, 3) Coefficient of Linear Thermal Expansion - ASTM E228, 4) Fracture Toughness - ASTM E399, 5) Brinell Hardness - ASTM E10, 6) Rockwell Hardness - ASTM E18, 7) Micro Vickers Hardness - ASTM E92, 8) Knoop Hardness - ASTM E92, 9) Macro Vickers Hardness - ASTM E92, 10) Stress Rupture / Creep Rupture - ASTM E139, 11) Stress Rupture (Combination) - ASTM E292, 12) Room Temperature Tensile - ASTM E8, 13) Elevated Room Temperature Tensile - ASTM E21, 14) Decarburization - ASTM E1077 15) Delta Ferrite - AMS 2315, 16) Grain Size - ASTM E112, 17) Inclusion Content/Microcleanliness - ASTM E45, 18) Intergranular Attach - ASTM A262, 19) Intergranular Corrosion - ASTM A262, 20) Macro Etch & Testing - ASTM A604/E381, 21) Pitting Corrosion - ASTM A923, 22) Crevice Corrosion -ASTM G48, 23) Hardness Conversions - ASTM E140, 24) XRF - ASTM E572/E1085/E2465, 25) OES - ASTM E415/E1086, 26) COM - ASTM E1019, 27) FUS - ASTM E1019, 28) MS - Carpenter Methods 206.8500/206.8530

Rebecca A Roberts 08/08/2023

REBECCA ROBERTS
GROUP LEADER - QUALITY
Carpenter Technology Corporation

Appendix G. Certificate of Tests for 4340 steel Heat J5385

CARPENTER TECHNOLOGY

Certificate ID : 000010080716_0001
Production Order : 10080716
Heat Number : J5385

Certificate of Tests

PRODUCT DESCRIPTION :
4340
NORMALIZED, TEMPERED, PEELED, POLISHED

SPECIFICATIONS :
AMS 2300 Rev M 05/01/2020,
AMS 6415 REV U 12/01/2016,
AMS 6414 Rev M 12/01/2016,
299-947-055 REV AH 10/29/2016 TYPE I Exception Letter 07/16/2021 PENDING,
SS9702 REV 4 07/26/2013 Gr 2 & 3 - Forg Stk,
EMS 4.1 REV E-1 05/17/2002,
S-SPEC-1 (S-1000) 04/01/2021,
S-SPEC-35 (S-400) 02/28/2021,
BMS 7-28 REV G 09/14/1987,
AMS 2301 Rev L 05/01/2020
S-SPEC-35 (S-400) 02/28/2021

SIZE :
0.625 (15.875 MM) ROUND BAR INGOT# 1

CHEMISTRY (WT%)
Chemical Composition
Ingot Average

Location	C	SI	MN	S	P	CR
Ingot 1	0.42	0.32	0.80	<0.001	0.007	0.86
Location	NI	MO	CU			
Ingot 1	1.94	0.26	0.08			

MACROSTRUCTURE
Macrostructure (DI)
Method: ASTM E340 & ASTM E381
TESTED AT 5.0001 X 5.0001 RCS

Location	PHOTO	RESULT
1A1	E-381 (S)	1
	E-381 (R)	1
	E-381 (C)	1
1X1	E-381 (S)	1
	E-381 (R)	1
	E-381 (C)	1

This test was performed at Carpenter Technology Corporation - Athens Operations, 22110 Thomas L Hammons Road, Tanner, AL 35671.

Page 2 of 7

The certification is made to the customer printed on the form. Carpenter neither makes, nor assumes responsibility for any representation or certification to other parties.(Form E2-366)

CARPENTER TECHNOLOGY

Certificate ID : 000010080716_0001
Production Order : 10080716
Heat Number : J5385

Certificate of Tests

Macrostructure (DI)
Method: ASTM A604/A604M & ASTM E340
TESTED AT 5.0001 X 5.0001 RCS

Location	PHOTO	RESULT
1A1	ASTM A-604 (1)	A
	ASTM A-604 (2)	A
	ASTM A-604 (3)	A
	ASTM A-604 (4)	A
1X1	ASTM A-604 (1)	A
	ASTM A-604 (2)	A
	ASTM A-604 (3)	A
	ASTM A-604 (4)	A

This test was performed at Carpenter Technology Corporation - Athens Operations, 22110 Thomas L Hammons Road, Tanner, AL 35671.

Macrostructure (DI)
Method: ASTM E340 & ASTM E381
TESTED AT 0.7950 RND

Location	PHOTO	RESULT
GP	E-381 (S)	1
	E-381 (R)	1
	E-381 (C)	1
GQ	E-381 (S)	1
	E-381 (R)	1
	E-381 (C)	1
GR	E-381 (S)	1
	E-381 (R)	1
	E-381 (C)	1
GS	E-381 (S)	1
	E-381 (R)	1
	E-381 (C)	1

This test was performed at Carpenter Technology Corporation - Reading Operations, 101 West Bern Street, Reading, PA 19601

Macrostructure (DI)
Method: ASTM A604/A604M & ASTM E340
TESTED AT 0.7950 RND

Location	PHOTO	RESULT
GT	ASTM A-604 (1)	A
	ASTM A-604 (2)	A
	ASTM A-604 (3)	A
	ASTM A-604 (4)	A
GU	ASTM A-604 (1)	A
	ASTM A-604 (2)	A
	ASTM A-604 (3)	A
	ASTM A-604 (4)	A
GV	ASTM A-604 (1)	A

CARPENTER TECHNOLOGY

Certificate ID : 000010080716_0001
Production Order : 10080716
Heat Number : J5385

Certificate of Tests

	ASTM A-604 (2) A
	ASTM A-604 (3) A
	ASTM A-604 (4) A
GW	ASTM A-604 (1) A
	ASTM A-604 (2) A
	ASTM A-604 (3) A
	ASTM A-604 (4) A

This test was performed at Carpenter Technology Corporation - Reading Operations, 101 West Bern Street, Reading, PA 19601

MICROSTRUCTURE

Micro Inclusion JK
Method: ASTM E45 (Method D)

Location	A (T)	A (H)	B (T)	B (H)	C (T)	C (H)	D (T)	D (H)
1A1	0	0	1.0	0	0	0	0	0
1X1	0	0	0	0	0	0	0	0

The worst field and total rateable fields frequency requirements were found to be within applicable specification limits.

Micro Inclusion JK
Method: ASTM E45 (Method A)

Location	A (T)	A (H)	B (T)	B (H)	C (T)	C (H)	D (T)	D (H)
1A1	0	0	1.0	0	0	0	0	0
1X1	0	0	0	0	0	0	0	0

The worst field and total rateable fields frequency requirements were found to be within applicable specification limits.

Micro Chem Band

Location	PHOTO	RESULT
15	Microhardness (RC Spread)	3.5

Test pieces heat treated to 1,500 °F, 30 MIN, OT prior to testing

Micro Decarburization
Decarburization per ASTM E1077: FREE
Test pieces heat treated to 1,550 °F, 30 MIN, OT prior to testing

Micro Grain Size
Method: ASTM E112

Location	GRAIN SIZE
GO	8.5

Test pieces heat treated to 1,575 °F, 1 H, WT prior to testing

CARPENTER TECHNOLOGY

Certificate ID : 000010080716_0001
Production Order : 10080716
Heat Number : J5385

Certificate of Tests

MECHANICAL PROPERTIES

Jominy Hardenability

Method: ASTM A255

Location	16THS	HRC
1X1	1	57.8
1X1	2	57.7
1X1	3	57.3
1X1	4	57.5
1X1	5	57.2
1X1	6	56.6
1X1	7	56.1
1X1	8	56.6
1X1	9	56.0
1X1	10	56.6
1X1	11	56.0
1X1	12	56.2
1X1	14	55.8
1X1	16	55.9
1X1	18	56.5
1X1	20	56.1
1X1	24	55.9
1X1	28	56.2
1X1	32	55.3

Test pieces heat treated to 1,600 °F, 1 H, AC / 1,550 °F, 30 MIN, WT prior to testing

Hardness

Method: ASTM E18 & ASTM A370

Location	RADIAL LOC.	RESULT(S) HRC
GK	MID-RADIUS	21.4
GL	MID-RADIUS	23.0

CAPABILITY MECHANICAL PROPERTIES

Cap Tension

Method: ASTM E8/E8M & ASTM A370

TESTED AT 5.0001 X 5.0001 RCS

ORIENTATION: TRANSVERSE

Location	RADIAL LOC.	UTS (KSI)	YS (0.2)KSI	ELONG (4D)%	RA %
1A1	CENTER	270	222	10	35
1A1	CENTER	270	223	11	44
1X1	CENTER	270	222	11	44
1X1	CENTER	270	222	11	45

Test pieces heat treated to 1,650 °F, 1 H, AC / 1,500 °F, 1 H, OT / 475 °F, 2 H, AC / 475 °F, 2 H, AC prior to testing

A .505" Rd. tensile specimen was used.

CARPENTER TECHNOLOGY

Certificate ID : 000010080716_0001
Production Order : 10080716
Heat Number : J5385

Certificate of Tests

Cap Tension
Method: ASTM E8/E8M & ASTM A370
TESTED AT 5.0001 X 5.0001 RCS

ORIENTATION:		TRANSVERSE			
Location	RADIAL LOC.	UTS (KSI)	YS (0.2)KSI	ELONG (4D)%	RA %
1A1	MID-RADIUS	269	222	12	45
1A1	MID-RADIUS	271	222	12	45
1X1	MID-RADIUS	267	220	12	46
1X1	MID-RADIUS	268	221	12	47

Test pieces heat treated to 1,650 °F, 1 H, AC / 1,500 °F, 1 H, OT / 475 °F, 2 H, AC / 475 °F, 2 H, AC prior to testing
A .505" Rd. tensile specimen was used.

MAGNETIC PARTICLE
Magnetic Particle
Method: AMS 2300

Location	F	S
1A1	0	0
1X1	0	0

This test was performed at PRODUCT EVALUATION SYSTEM INC, DONOHOE RD, LATROBE, PA, 15650 Report No. LTB REPORT#J5385-1

CERTIFICATION STATEMENT
Material tested in accordance with AMS 2300 to satisfy the requirements of AMS 2301

Subcritically Annealed.

This material has been ARC-VAR melted

GEAG SUPPLIER CODE - 21100/CARPENTER, T9406/ATHENS, 51904/LATROBE

MATERIAL CONFORMS TO THE REQUIREMENTS OF AMS 6414.

Process qualification in accordance with 4.2.3 and 4.2.3.1 of AMS 2300 has been completed

AMS 6414M (Supersedes MIL-S-8844D Notice 1) AMS 6415U (Replaces AMS-S-5000A/MIL-S-5000E) Except VAR

All bars grade verified by Spectrotest.

Carpenter Technology Corporation supply chain controls take into account Dodd Frank Act requirements regarding conflict minerals

3:1 minimum reduction ratio from ingot to final product

Country of origin (Manufacturing & Melting): USA

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CARPENTER TECHNOLOGY

Certificate ID : 000010080716_0001
Production Order : 10080716
Heat Number : J5385

Certificate of Tests

Testing methods for chemical analysis tested at Latrobe Specialty Metals are as follows: C & S = Combustion N, O & H = Fusion Si, Mn, W, Cr, V, Ni, Mo, Co, Cu, Ti >0.1%, Cb, Ta, Fe, Al >1 %, Zr = X-ray or OES P, Al <1%, B, Ti <0.1 %, Pb, Mg, Ca, As = OES Sn per procedure X-ray or OES. Other testing methods not listed above have been conducted per certified material specification(s).

Unless otherwise stated, the tests were performed to the latest revision of the standards listed below: 1) Bend Test - ASTM E290, 2) Charpy Impact - ASTM E23, 3) Coefficient of Linear Thermal Expansion - ASTM E228, 4) Fracture Toughness - ASTM E399, 5) Brinell Hardness - ASTM E10, 6) Rockwell Hardness - ASTM E18, 7) Micro Vickers Hardness - ASTM E92, 8) Knoop Hardness - ASTM E92, 9) Macro Vickers Hardness - ASTM E92, 10) Stress Rupture / Creep Rupture - ASTM E139, 11) Stress Rupture (Combination) - ASTM E292, 12) Room Temperature Tensile - ASTM E8, 13) Elevated Room Temperature Tensile - ASTM E21, 14) Decarburization - ASTM E1077 15) Delta Ferrite - AMS 2315, 16) Grain Size - ASTM E112, 17) Inclusion Content/Microcleanliness - ASTM E45, 18) Intergranular Attach - ASTM A262, 19) Intergranular Corrosion - ASTM A262, 20) Macro Etch & Testing - ASTM A604/E381, 21) Pitting Corrosion - ASTM A923, 22) Crevice Corrosion -ASTM G48, 23) Hardness Conversions - ASTM E140, 24) XRF - ASTM E572/E1085/E2465, 25) OES - ASTM E415/E1086, 26) COM - ASTM E1019, 27) FUS - ASTM E1019, 28) MS - Carpenter Methods 206.8500/206.8530

Breanna Lickenfelt 02/10/2023

BREANNA LICKENFELT
ADMINISTRATOR II - QUALITY
Carpenter Technology Corporation

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Appendix H. Certificate of Tests for 4340 steel Heat J4943

CARPENTER TECHNOLOGY

Certification ID: 000010086489_0001

CARPENTER TECHNOLOGY CORP.
LATROBE OPERATIONS (PA)
2626 LIGONIER STREET
LATROBE PA 15650

Certificate of Tests

Sales Order Information	
Sales Order/Item:	60139/10
Customer PO/Item:	27-159975/000001

Delivery Information	
Delivery:	80243051
Picked Date:	03/27/2023
Quantity Shipped:	1,223 LB 1611

Production Information	
Production Order:	10086489
Heat Number:	J5803
Ingot(s) Shipped*:	2

The recording of false, fictitious or fraudulent statements or entries on this document may be punished as a felony under federal statues including federal law, Title 18, Chapter 47.
The values and other technical data represent the results of analyses and tests made on samples collected from the total lot. Original data records can be traced by reference to the Carpenter order number.
During the manufacturing process, this material has not come in direct contact with Mercury or any of its compounds. The material has not come in contact with any radioactive sources, Cobalt 60, Radium or Alpha-Source nor devices employing a single boundary of containment. Material is also weld free.

Material has been melted in USA or qualifying country to DFARS requirements 252.225-7014 with alternate 1 for qualifying country 225.872.1, superseded by DFARS requirements DFARS 252.225-7008 and 252.225-7009.

This order was manufactured in accordance with Carpenter Specialty Alloys Operations Quality Program Manual, Revision 38 dated 08/21/2022.
Carpenter Technology Corporation is registered to Quality Management System Standards: ISO 9001, AS9120 and AS9100.
This certificate of test is Type 3.1 prepared in accordance with EN 10204 (DIN 50049).
We certify this material to have been manufactured, inspected, and tested; and found the results to conform to all drawing and/or specification requirements and order requirements as applicable.
Carpenter Technology third party accreditation certificates are available on the company website: https://www.carpentertechnology.com/quality-certifications

Decision Rule: Unless otherwise specified in a customer/industry specification, Carpenter Technology Corporation will determine acceptability of any test result by comparison of the result with the specification limits, without any additional consideration of the measurement uncertainty. When requested, Carpenter Technology Corporation will provide uncertainty budgets for any test result that is not addressed by the industry standard. When a Decision Rule is defined in a customer/industry specification it will supersede the Corporate Decision Rule.

*Ingot(s) Shipped represents the ingots that were shipped on the specified delivery. The material produced and certified may include additional ingots that were not shipped.

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CARPENTER TECHNOLOGY

Certificate ID: 000010086489_0001
Production Order: 10086489
Heat Number: J5803

Certificate of Tests

PRODUCT DESCRIPTION :
4340
NORMALIZED, TEMPERED, PEELED, POLISHED

SPECIFICATIONS :
AMS 2300 Rev M 05/01/2020,
299-947-055 REV AH 10/29/2016 TYPE I Exception Letter 07/16/2021 PENDING,
SS9702 REV 4 07/26/2013 Gr 2 & 3 - Forg Stk,
EMS 4.1 REV E-1 05/17/2002,
S-SPEC-1 (S-1000) 04/01/2021,
S-SPEC-35 (S-400) 02/28/2021,
BMS 7-28 REV G 09/14/1987,
AMS 2301 Rev L 05/01/2020
AMS 6414 Rev M 12/01/2016
AMS 6415 REV V 11/01/2022
S-SPEC-35 (S-400) 02/28/2021

SIZE :
0.625 (15.875 MM) ROUND BAR INGOT# 2

CHEMISTRY (WT%)

Chemical Composition
Ingot Average

Location	C	SI	MN	S	P	CR
Ingot 2	0.42	0.32	0.77	0.001	0.003	0.84
Location	NI	MO	CU			
Ingot 2	1.93	0.26	0.07			

MACROSTRUCTURE

Macrostructure (DI)
Method: ASTM E340 & ASTM E381
TESTED AT 5.0001 X 5.0001 RCS

Location	PHOTO	RESULT
2A1	E-381 (S)	1
	E-381 (R)	1
	E-381 (C)	1
2X1	E-381 (S)	1
	E-381 (R)	1
	E-381 (C)	1

This test was performed at Carpenter Technology Corporation - Athens Operations, 22110 Thomas L Hammons Road, Tanner, AL 35671.

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CARPENTER TECHNOLOGY

Certificate ID : 000010086489_0001
Production Order : 10086489
Heat Number : J5803

Certificate of Tests

Macrostructure (DI)
Method: ASTM A604/A604M & ASTM E340
TESTED AT 5.0001 X 5.0001 RCS

Location	PHOTO	RESULT
2A1	ASTM A-604 (1)	A
	ASTM A-604 (2)	A
	ASTM A-604 (3)	A
	ASTM A-604 (4)	A
2X1	ASTM A-604 (1)	A
	ASTM A-604 (2)	A
	ASTM A-604 (3)	A
	ASTM A-604 (4)	A

This test was performed at Carpenter Technology Corporation - Athens Operations, 22110 Thomas L Hammons Road, Tanner, AL 35671.

Macrostructure (DI)
Method: ASTM E340 & ASTM E381
TESTED AT 0.7950 RND

Location	PHOTO	RESULT
4O	E-381 (S)	1
	E-381 (R)	1
	E-381 (C)	1
4P	E-381 (S)	1
	E-381 (R)	1
	E-381 (C)	1
4Q	E-381 (S)	1
	E-381 (R)	1
	E-381 (C)	1
4R	E-381 (S)	1
	E-381 (R)	1
	E-381 (C)	1

This test was performed at Carpenter Technology Corporation - Reading Operations, 101 West Bern Street, Reading, PA 19601

Macrostructure (DI)
Method: ASTM A604/A604M & ASTM E340
TESTED AT 0.7950 RND

Location	PHOTO	RESULT
4S	ASTM A-604 (1)	A
	ASTM A-604 (2)	A
	ASTM A-604 (3)	A
	ASTM A-604 (4)	A
4T	ASTM A-604 (1)	A
	ASTM A-604 (2)	A
	ASTM A-604 (3)	A
	ASTM A-604 (4)	A

CARPENTER TECHNOLOGY

Certificate ID : 000010086489_0001
Production Order : 10086489
Heat Number : J5803

Certificate of Tests

4U	ASTM A-604 (1) A
	ASTM A-604 (2) A
	ASTM A-604 (3) A
	ASTM A-604 (4) A
4V	ASTM A-604 (1) A
	ASTM A-604 (2) A
	ASTM A-604 (3) A
	ASTM A-604 (4) A

This test was performed at Carpenter Technology Corporation - Reading Operations, 101 West Bern Street, Reading, PA 19601

MICROSTRUCTURE

Micro Inclusion JK

Method: ASTM E45 (Method D)

Location	A (T)	A (H)	B (T)	B (H)	C (T)	C (H)	D (T)	D (H)
2A1	0	0	0	0	0	0	0	0
2X1	0	0	0	0	0	0	0	0

The worst field and total rateable fields frequency requirements were found to be within applicable specification limits.

Micro Chem Band

Location	PHOTO	RESULT
TL	Microhardness (RC Spread)	1.1

Test pieces heat treated to 1,500 °F, 30 MIN, OT prior to testing

Micro Decarburization

Decarburization per ASTM E1077: FREE

Test pieces heat treated to 1,550 °F, 30 MIN, OT prior to testing

Micro Grain Size

Method: ASTM E112

Location	GRAIN SIZE
4N	8.5

Test pieces heat treated to 1,575 °F, 1 H, WT prior to testing

Micro Inclusion JK

Method: ASTM E45 (Method A)

Location	A (T)	A (H)	B (T)	B (H)	C (T)	C (H)	D (T)	D (H)
2A1	0	0	0	0	0	0	0	0
2X1	0	0	0	0	0	0	0	0

The worst field and total rateable fields frequency requirements were found to be within applicable specification limits.

CARPENTER TECHNOLOGY

Certificate ID : 000010086489_0001
Production Order : 10086489
Heat Number : J5803

Certificate of Tests

MECHANICAL PROPERTIES

Jominy Hardenability

Method: ASTM A255

Location	16THS	HRC
1X1	1	58.9
1X1	2	59.7
1X1	3	58.2
1X1	4	58.2
1X1	5	58.4
1X1	6	57.7
1X1	7	57.0
1X1	8	57.5
1X1	9	57.5
1X1	10	56.6
1X1	11	56.6
1X1	12	56.8
1X1	14	56.1
1X1	16	55.5
1X1	18	56.3
1X1	20	56.0
1X1	24	55.8
1X1	28	55.6
1X1	32	56.1

Test pieces heat treated to 1,600 °F, 1 H, AC / 1,550 °F, 30 MIN, WT prior to testing

Hardness

Method: ASTM E18 & ASTM A370

Location	RADIAL LOC.	RESULT(S) HRC
4J	MID-RADIUS	22.4
4K	MID-RADIUS	21.0

CAPABILITY MECHANICAL PROPERTIES

Cap Tension

Method: ASTM E8/E8M & ASTM A370

TESTED AT 5.0001 X 5.0001 RCS

ORIENTATION: TRANSVERSE

Location	RADIAL LOC.	UTS (KSI)	YS (0.2)KSI	ELONG (4D)%	RA %
2A1	CENTER	270	223	11	39
2A1	CENTER	270	222	11	42
2X1	CENTER	270	223	11	44
2X1	CENTER	270	223	12	45

Test pieces heat treated to 1,650 °F, 1 H, AC / 1,500 °F, 1 H, OT / 475 °F, 2 H, AC / 475 °F, 2 H, AC prior to testing

A .505" Rd. tensile specimen was used.

CARPENTER TECHNOLOGY

Certificate ID: 000010086489_0001
Production Order: 10086489
Heat Number: J5803

Certificate of Tests

Cap Tension
Method: ASTM E8/E8M & ASTM A370
TESTED AT 5.0001 X 5.0001 RCS

ORIENTATION:		TRANSVERSE			
Location	RADIAL LOC.	UTS (KSI)	YS (0.2)KSI	ELONG (4D)%	RA %
2A1	MID-RADIUS	268	222	11	43
2A1	MID-RADIUS	268	222	12	46
2X1	MID-RADIUS	268	222	11	44
2X1	MID-RADIUS	269	223	12	46

Test pieces heat treated to 1,650 °F, 1 H, AC / 1,500 °F, 1 H, OT / 475 °F, 2 H, AC / 475 °F, 2 H, AC prior to testing
A .505" Rd. tensile specimen was used.

MAGNETIC PARTICLE
Magnetic Particle
Method: AMS 2300

Location	F	S
2A1	0	0
2X1	0	0

This test was performed at Solmet Technologies, 2716 Shepler Church Ave SW, Canton, OH 44706 Report No. LAT-5803-2

CERTIFICATION STATEMENT
Material tested in accordance with AMS 2300 to satisfy the requirements of AMS 2301

Subcritically Annealed

This material has been ARC-VAR melted

GEAG SUPPLIER CODE - 21100/CARPENTER, T9406/ATHENS, 51904/LATROBE

MATERIAL CONFORMS TO THE REQUIREMENTS OF AMS 6414.

Process qualification in accordance with 4.2.3 and 4.2.3.1 of AMS 2300 has been completed

AMS 6414M (Supersedes MIL-S-8844D Notice 1) AMS 6415U (Replaces AMS-S-5000A/MIL-S-5000E) Except VAR

All bars grade verified by Spectrotest.

Carpenter Technology Corporation supply chain controls take into account Dodd Frank Act requirements regarding conflict minerals

3:1 minimum reduction ratio from ingot to final product

Country of origin (Manufacturing & Melting): USA

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CARPENTER TECHNOLOGY

Certificate ID: 000010086489_0001
Production Order: 10086489
Heat Number: J5803

Certificate of Tests

Testing methods for chemical analysis tested at Latrobe Specialty Metals are as follows: C & S = Combustion N, O & H = Fusion Si, Mn, W, Cr, V, Ni, Mo, Co, Cu, Ti >0.1%, Cb, Ta, Fe, Al >1 %, Zr = X-ray or OES P, Al <1%, B, Ti <0.1 %, Pb, Mg, Ca, As = OES Sn per procedure X-ray or OES. Other testing methods not listed above have been conducted per certified material specification(s).

Unless otherwise stated, the tests were performed to the latest revision of the standards listed below: 1) Bend Test - ASTM E290, 2) Charpy Impact - ASTM E23, 3) Coefficient of Linear Thermal Expansion - ASTM E228, 4) Fracture Toughness - ASTM E399, 5) Brinell Hardness - ASTM E10, 6) Rockwell Hardness - ASTM E18, 7) Micro Vickers Hardness - ASTM E92, 8) Knoop Hardness - ASTM E92, 9) Macro Vickers Hardness - ASTM E92, 10) Stress Rupture / Creep Rupture - ASTM E139, 11) Stress Rupture (Combination) - ASTM E292, 12) Room Temperature Tensile - ASTM E8, 13) Elevated Room Temperature Tensile - ASTM E21, 14) Decarburization - ASTM E1077 15) Delta Ferrite - AMS 2315, 16) Grain Size - ASTM E112, 17) Inclusion Content/Microcleanliness - ASTM E45, 18) Intergranular Attach - ASTM A262, 19) Intergranular Corrosion - ASTM A262, 20) Macro Etch & Testing - ASTM A604/E381, 21) Pitting Corrosion - ASTM A923, 22) Crevice Corrosion -ASTM G48, 23) Hardness Conversions - ASTM E140, 24) XRF - ASTM E572/E1085/E2465, 25) OES - ASTM E415/E1086, 26) COM - ASTM E1019, 27) FUS - ASTM E1019, 28) MS - Carpenter Methods 206.8500/206.8530

Breanna Lickenfelt

03/27/2023

BREANNA LICKENFELT
ADMINISTRATOR II - QUALITY
Carpenter Technology Corporation

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Appendix I. Certificate of Tests for 4340 steel Heat J4943

CARPENTER TECHNOLOGY

Certificate ID : 000010112851_0001
Production Order : 10112851
Heat Number : J6489

Certificate of Tests

PRODUCT DESCRIPTION :
4340 NORMALIZED, TEMPERED, CENTERLESS GROUND AIRCRAFT QUALITY

SPECIFICATIONS :
299-947-055 REV AH 10/29/2016 TYPE I Exception Letter 07/16/2021 PENDING,
AMS 2300 Rev M 05/01/2020
AMS 2301 Rev L 05/01/2020
AMS 2761 07/01/2020
AMS 6414 REV N 03/01/2023
AMS 6415 REV V 11/01/2022
AMS 6484 REV F 11/01/2022,
AMS-S-5000A 03/01/2007 SUPERSEDED,
BMS 7-28 REV G 09/14/1987
DMS 1555 REV H 07/02/1991 GRADE A,
EMS 4.1 REV E-1 05/17/2002,
MIL-S-5000E NOTICE 2 08/11/2000 SUPERSEDED,
MIL-S-8844D NOTICE 1 04/25/1994 4340 - SUPERSEDED,

SIZE :
0.76 (19.304 MM) S# 57145 ROUND BAR INGOT #1

CHEMISTRY (WT%)
Chemistry Check

Location	C	SI	MN	S	P	CR
1A1	0.43	0.32	0.76	0.001	0.006	0.82
1X1	0.43	0.32	0.72	0.001	0.006	0.83

Location	NI	MO	CU	AL
1A1	1.84	0.26	0.06	0.033
1X1	1.84	0.26	0.06	0.032

MACROSTRUCTURE
Macrostructure (DI)
Method: ASTM A604/A604M & ASTM E340
TESTED AT 5.0001 X 5.0001 RCS
ETCHANT: 50% HCL/50% WATER

Location	PHOTO	RESULT
1A1	ASTM A-604 (1)	A
	ASTM A-604 (2)	A
	ASTM A-604 (3)	A
	ASTM A-604 (4)	A
1X1	ASTM A-604 (1)	A
	ASTM A-604 (2)	A
	ASTM A-604 (3)	A
	ASTM A-604 (4)	A

This test was performed at Carpenter Technology Corporation - Athens Operations, 22110 Thomas L Hammons Road, Tanner, AL 35671.

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The certification is made to the customer printed on the form. Carpenter neither makes, nor assumes responsibility for any representation or certification to other parties.(Form E2-366)

CARPENTER TECHNOLOGY

Certificate ID : 000010112851_0001
Production Order : 10112851
Heat Number : J6489

Certificate of Tests

Macrostructure (DI)
Method: ASTM E340 & ASTM E381
TESTED AT 5.0001 X 5.0001 RCS
ETCHANT: 50% HCL/50% WATER

Location	PHOTO	RESULT
1A1	E-381 (S)	1
	E-381 (R)	1
	E-381 (C)	1
1X1	E-381 (S)	1
	E-381 (R)	1
	E-381 (C)	1

This test was performed at Carpenter Technology Corporation - Athens Operations, 22110 Thomas L Hammons Road, Tanner, AL 35671.

Macrostructure (DI)
Method: ASTM A604/A604M & ASTM E340
TESTED AT 0.8500 RND
ETCHANT: 50% HCL/50% WATER

Location	PHOTO	RESULT
ALL	ASTM A-604 (1)	A
	ASTM A-604 (2)	A
	ASTM A-604 (3)	A
	ASTM A-604 (4)	A

This test was performed at Carpenter Technology Corporation - Reading Operations, 101 West Bern Street, Reading, PA 19601

Macrostructure (DI)
Method: ASTM E340 & ASTM E381
TESTED AT 0.8500 RND
ETCHANT: 50% HCL/50% WATER

Location	PHOTO	RESULT
7K	E-381 (S)	1
	E-381 (R)	1
	E-381 (C)	1

This test was performed at Carpenter Technology Corporation - Reading Operations, 101 West Bern Street, Reading, PA 19601

CARPENTER TECHNOLOGY

Certificate ID : 000010112851_0001
Production Order : 10112851
Heat Number : J6489

Certificate of Tests

MICROSTRUCTURE
Micro Decarburization
Decarburization per ASTM E1077: FREE
Test pieces heat treated to 1,550 °F, 30 MIN, OT prior to testing

Micro Inclusion JK
Method: ASTM E45 (Method A)

Location	A (T)	A (H)	B (T)	B (H)	C (T)	C (H)	D (T)	D (H)
1A1	0	0	0	0	0	0	0	0
1X1	0	0	0	0	0	0	0	0

The worst field and total rateable fields frequency requirements were found to be within applicable specification limits.

Micro Inclusion JK
Method: ASTM E45 (Method D)

Location	A (T)	A (H)	B (T)	B (H)	C (T)	C (H)	D (T)	D (H)
1A1	0	0	0	0	0	0	0	0
1X1	0	0	0	0	0	0	0	0

The worst field and total rateable fields frequency requirements were found to be within applicable specification limits.

Micro Chem Band

Location	PHOTO	RESULT
5I	Microhardness (RC Spread)	1.9

Test pieces heat treated to 1,500 °F, 30 MIN, OT prior to testing

MECHANICAL PROPERTIES
Hardness
Method: ASTM E18 & ASTM A370

Location	RADIAL LOC.	RESULT(S) HRC
7I	Mid-Radius	23.2
7J	Mid-Radius	21.5

Jominy Hardenability
Method: ASTM A255

Location	16THS	HRC
1X1	1	59.6
	2	60.2
	3	58.9
	4	58.6
	5	58.2
	6	58.1
	7	57.4
	8	57.3
	9	57.9

CARPENTER TECHNOLOGY

Certificate ID : 000010112851_0001
Production Order : 10112851
Heat Number : J6489

Certificate of Tests

10	56.7
11	56.8
12	57.1
14	56.9
16	56.4
18	56.3
20	55.7
24	55.6
28	55.4
32	54.7

Test pieces heat treated to 1,600 °F, 1 H, AC / 1,550 °F, 30 MIN, WT prior to testing

CAPABILITY MICROSTRUCTURE

Cap Micro Grain Size
Method: ASTM E112

Location	GRAIN SIZE
5J	8

Test pieces heat treated to 1,575 °F, 1 H, WT prior to testing

Cap Micro Grain Size
Method: ASTM E112
ETCHANT: NITAL 4%
MAGNIFICATION: 100X

Location	GRAIN SIZE
7R	8

Test pieces heat treated to 1,575 °F, 1 H, WT prior to testing

CAPABILITY MECHANICAL PROPERTIES

Cap Tension
Method: ASTM E8/E8M & ASTM A370
TESTED AT 5.0001 X 5.0001 RCS
ORIENTATION: Transverse

Location	RADIAL LOC.	UTS (KSI)	YS (0.2)KSI	ELONG (4D)%	RA %
1A1	Center	272.0	225.1	11	45
1A1	Center	271.4	224.6	11	42
1X1	Center	272.3	225.7	12	42
1X1	Center	272.1	225.6	12	44

This test was performed at WESTMORELAND MECHANICAL TESTING AND RESEARCH INC, WESTMORELAND DR, YOUNGSTOWN, PA, 15650 Report No. 01-2300018260
Test pieces heat treated to 1,650 °F, 1 H, AC / 1,500 °F, 1 H, OT / 475 °F, 2 H, AC / 475 °F, 2 H, AC prior to testing
A .505" Rd. tensile specimen was used.

CARPENTER TECHNOLOGY

Certificate ID : 000010112851_0001
Production Order : 10112851
Heat Number : J6489

Certificate of Tests

Cap Tension
Method: ASTM E8/E8M & ASTM A370
TESTED AT 5.0001 X 5.0001 RCS

ORIENTATION:		Transverse			
Location	RADIAL LOC.	UTS (KSI)	YS (0.2)KSI	ELONG (4D)%	RA %
1A1	Mid-Radius	266.7	222.1	12	46
1A1	Mid-Radius	268.8	223.0	10	36
1X1	Mid-Radius	271.1	225.0	11	43
1X1	Mid-Radius	270.5	224.1	14	48

This test was performed at WESTMORELAND MECHANICAL TESTING AND RESEARCH INC, WESTMORELAND DR, YOUNGSTOWN, PA, 15650 Report No. 01-2300018377
Test pieces heat treated to 1,650 °F, 1 H, AC / 1,500 °F, 1 H, OT / 475 °F, 2 H, AC / 475 °F, 2 H, AC prior to testing
A .505" Rd. tensile specimen was used.

MAGNETIC PARTICLE

Magnetic Particle
Method: AMS 2300

Location	F	S
1A1	0	0
1X1	0	0

CERTIFICATION STATEMENT

Manufactured and tested in accordance with AMS 6414 which supersedes MIL-S-8844D

Manufactured and tested in accordance with applicable specifications AMS 6415 and AMS 6484 which supersede AMS-S-5000A

Process qualification in accordance with 4.2.3 and 4.2.3.1 of AMS 2300 has been completed

All bars grade verified by Spectrotest.

No chemical banding observed metallograph-ically.

This material has been ARC-VAR melted

Country of origin (Manufacturing & Melting): USA

Testing methods for chemical analysis tested at Latrobe Specialty Metals are as follows: C & S = Combustion N, O & H = Fusion Si, Mn, W, Cr, V, Ni, Mo, Co, Cu, Ti >0.1%, Cb, Ta, Fe, Al >1 %, Zr = X-ray or OES P, Al <1%, B, Ti <0.1 %, Pb, Mg, Ca, As = OES Sn per procedure X-ray or OES. Other testing methods not listed above have been conducted per certified material specification(s).

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CARPENTER TECHNOLOGY

Certificate ID : 000010112851_0001
Production Order : 10112851
Heat Number : J6489

Certificate of Tests

Unless otherwise stated, the tests were performed to the latest revision of the standards listed below: 1) Bend Test - ASTM E290, 2) Charpy Impact - ASTM E23, 3) Coefficient of Linear Thermal Expansion - ASTM E228, 4) Fracture Toughness - ASTM E399, 5) Brinell Hardness - ASTM E10, 6) Rockwell Hardness - ASTM E18, 7) Micro Vickers Hardness - ASTM E92, 8) Knoop Hardness - ASTM E92, 9) Macro Vickers Hardness - ASTM E92, 10) Stress Rupture / Creep Rupture - ASTM E139, 11) Stress Rupture (Combination) - ASTM E292, 12) Room Temperature Tensile - ASTM E8, 13) Elevated Room Temperature Tensile - ASTM E21, 14) Decarburization - ASTM E1077 15) Delta Ferrite - AMS 2315, 16) Grain Size - ASTM E112, 17) Inclusion Content/Microcleanliness - ASTM E45, 18) Intergranular Attach - ASTM A262, 19) Intergranular Corrosion - ASTM A262, 20) Macro Etch & Testing - ASTM A604/E381, 21) Pitting Corrosion - ASTM A923, 22) Crevice Corrosion -ASTM G48, 23) Hardness Conversions - ASTM E140, 24) XRF - ASTM E572/E1085/E2465, 25) OES - ASTM E415/E1086, 26) COM - ASTM E1019, 27) FUS - ASTM E1019, 28) MS - Carpenter Methods 206.8500/206.8530

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Appendix J. Individual hardness measurements and Charpy results for Heats J4906, J4943, J5385, J5803, J6489

	Heat J4906		Heat J4943		Heat J5385		Heat J5803		Heat J6489	
Machine	KV (J)	Hardness	KV (J)	Hardness	KV (J)	Hardness	KV (J)	Hardness	KV (J)	Hardness
SI	116.29	31.7	124.56	31.2	113.39		115.72	30.95	117.38	30.95
SI	121.75	31.95	125.00	31.55	117.79		119.72	31.5	125.17	31.5
SI	114.93	31.8	117.80	31.55	115.28		115.72	31.3	117.58	31.6
SI	117.26	32.05	118.86	31.55	113.47		120.91	31.15	117.04	31.55
SI	120.15	31.95	129.03	31.7	119.77		124.47	31.35	129.00	31.4
SI	116.88	31.85	121.99	31.55	117.71		115.54	31.35	124.82	31.65
SI	116.25	31.95	129.40	31.65	117.17		120.45	31.25	124.09	31.55
SI	118.97	31.85	120.16	31.85	119.08		121.64	31.25	123.27	31.2
SI	119.70	31.9	120.16	31.6	111.68		119.27	31.5	122.81	32
SI	118.42	31.8	129.21	31.35	119.33		116.00	31.4	119.53	31.8
SI	114.16		125.27		121.43	31.30	122.55		127.29	
SI	121.61		119.53		120.24	31.70	124.47		129.50	
SI	121.79		125.55		115.61	31.80	122.92		119.23	
SI	121.43		119.16		117.79	31.85	129.88		111.46	
SI	118.85		122.81		129.66	31.40	116.99		123.27	
SI	117.61		124.36		118.19	31.70	116.99		127.66	
SI	118.06		121.99		122.60	31.50	116.72		121.05	
SI	115.88		116.34		112.52	31.80	123.46		120.53	
SI	120.15		118.43		115.41	31.90	118.45		118.89	
SI	122.25		125.18		126.71	31.45	119.36		115.63	
SI	116.06		124.45		122.78		117.81		115.72	
SI	122.69		123.54		119.50		117.36		124.55	
SI	114.78		120.44		117.63		118.18		121.08	
SI	117.05		124.09		124.64		115.90		127.48	
SI	117.77		119.43		124.37		115.72		117.44	
TO	118.57	31.45	115.57	31.70	117.77		122.59	31.50	130.14	31.15
TO	118.76	32.00	118.86	31.60	119.02		116.54	31.20	113.59	31.60
TO	114.50	31.75	116.97	31.80	118.83		117.89	31.40	121.13	32.25
TO	117.90	31.65	118.39	31.50	113.17		124.59	31.40	123.22	31.50
TO	118.40	31.60	123.86	31.45	119.68		118.36	31.30	112.82	31.40
TO	116.45	31.60	113.19	31.05	127.43		120.06	31.40	115.76	31.65
TO	111.55	32.00	118.39	31.80	122.87		121.86	31.55	121.62	31.45
TO	114.76	31.80	121.69	31.45	122.33		122.61	31.50	118.97	31.70
TO	119.67	31.55	117.16	31.40	119.52		114.49	31.50	122.19	31.85
TO	118.45	31.90	114.41	31.55	119.14		120.72	31.50	125.96	32.05
TO	116.74		120.28		112.91	31.6	128.09		126.91	
TO	111.74		115.65		109.79	31.70	119.87		120.49	
TO	113.16		121.98		122.20	31.45	125.54		118.88	
TO	113.16		125.19		122.29	31.85	117.69		124.92	
TO	119.67		123.01		107.84	31.60	118.36		126.72	
TO	115.04		121.31		118.04	31.85	115.62		122.74	
TO	111.36		118.67		121.08	31.85	115.70		119.34	
TO	114.29		114.80		110.59	31.95	116.00		124.45	
TO	115.71		121.13		108.42	31.65	115.34		122.37	
TO	112.12		118.76		111.73	31.90	115.05		118.78	
TO	122.32		113.84		121.37		121.76		121.05	
TO	112.12		122.54		116.11		121.75		120.11	
TO	109.85		118.95		117.81		120.25		121.05	
TO	114.76		116.69		118.84		120.82		130.96	
TO	119.48		117.16		119.59		116.66		122.19	
TK	120.17	31.70	125.13	31.40	110.66		120.72	31.65	135.25	31.30
TK	119.47	31.85	118.81	31.20	123.78		127.57	31.45	120.78	31.45
TK	115.78	31.55	123.49	31.30	116.01		120.53	31.35	123.51	31.55
TK	117.47	31.75	126.07	31.85	118.62		126.63	31.85	123.73	31.40
TK	127.42	31.65	120.07	31.50	116.78		130.87	31.40	114.09	31.95
TK	121.62	31.80	131.15	31.70	111.39		122.28	32.05	124.51	31.15
TK	119.58	31.95	127.33	31.20	109.31		119.07	31.55	120.89	31.20
TK	118.57	31.65	125.88	31.65	123.75		119.07	31.55	126.07	31.30
TK	121.37	31.95	122.05	31.60	121.37		120.22	31.45	117.99	32.00
TK	117.63	31.70	127.54	31.80	124.79		128.51	31.40	120.80	31.10
TK	124.48		122.46		125.43	31.85	119.31		120.48	
TK	119.82		125.47		122.32	31.90	122.42		124.34	
TK	121.05		120.18		124.80	31.65	121.69		121.33	
TK	121.00		126.61		123.27	31.75	121.90		123.62	
TK	121.42		130.22		124.06	31.95	116.82		122.07	
TK	124.32		130.95		126.97	31.65	105.68		127.51	
TK	115.92		123.29		118.38	31.85	118.48		127.41	
TK	120.07		127.02		120.37	31.85	115.05		122.97	
TK	115.40		119.46		123.69	31.80	116.82		117.16	
TK	122.46		125.05		111.14	31.80	124.39		130.73	
TK	123.50		120.60		118.53		121.60		125.36	
TK	119.76		122.88		119.67		118.13		123.20	
TK	118.62		127.85		116.47		117.30		130.64	
TK	118.52		122.05		118.23		122.50		123.21	
TK	118.83		122.88		122.07		118.87		115.02	

Appendix K. Individual hardness measurements and Charpy results for Heats J5385 and J6489 (re-tempered)

Machine	KV (J)	Hardness	Energy	Hardness
TO	112.87	30.95	122.73	30.15
TO	121.50	31.15	115.79	30.5
TO	112.81	30.75	124.02	30.25
TO	117.81	30.95	122.31	30.45
TO	118.94	31.05	121.09	30.35
TO	118.95	30.85	121.46	30.45
TO	121.60	30.80		
TO	117.73	30.70		
TO	117.81	31.15		
TO	121.88	31.10		
TO	118.95			
TO	127.17			
TO	118.58			
TO	125.09			
TO	119.90			