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# Measurement of the structural damping ratio of some common materials at 293 K and 77 K in air

F. Micolon

October 2025

Electron-Ion Collider

**Brookhaven National Laboratory**

**U.S. Department of Energy**

USDOE Office of Science (SC), Nuclear Physics (NP)

# DISCLAIMER

# Measurement of the structural damping ratio of some common materials at 293 K and 77 K in air

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**Abstract.** The structural damping ratio of various materials has been measured at 293 K and 77 K through a rod bending excitation setup. The aim was to extract the material-dependent structural damping ratio as a first approach to in-vacuum damping. However, for simplicity, testing has been conducted in air with measures to minimize the effect of viscous damping from viscous drag. The setup and methodology are described in this paper, as well as the setup limitations and proposed ways to overcome these limitations for an improved setup. The results are presented in a summary table and discussed.

## 1. Introduction

A general trend in new particle accelerators projects is the reduction of transverse beam size, as this is useful to improve brightness for synchrotron light sources or luminosity for colliders. However, one downside is that it makes beam orbit stability – and so hardware position stability - proportionally more important [1][2]. To design particle accelerator supports with high stability, engineers typically work on limiting low-frequency resonances. But when that is not possible, or when a high stability is required up to a high frequency, some structural resonances can still be excited, and the resulting vibration amplitude needs to be assessed and put under control. The evaluation of the displacement triggered by these resonances requires the knowledge of the damping characteristics of the material being deformed. While in air the effective damping is a combination of material-dependent structural damping and viscous damping from air drag, in vacuum, only the structural damping component is present. In an attempt to approach values of structural damping values in this study, we tried to minimize the effect of air viscous damping.
While absolute damping values reported still include some amount of viscous drag damping, relative values are useful to show variations between materials in an identical test environment.
This study offers a determination of materials structural damping characteristics at room temperature (293 K) and around liquid nitrogen temperature (77 K) in air with efforts made to minimize air viscous damping.

## 2. Experimental methodology

*2.1 Test setup*

The test setup relies on measuring the vibration amplitude decay of a bending beam in a fixed-free configuration. Samples are Ø0.25 inch (Ø6.35 mm) rods with length of 8.5 inch (215.9 mm) for all samples tested both at 293 K and 77 K and length 12 inch (304 mm) for all samples tested excusively at 293 K.
The samples fixed-ends are clamped in a double-screw clamp in an attempt to limit the friction within the clamp assembly which would create artificial damping. When testing at 77K, a tubular

PTFE sleeve is fixed around the sample – without contact - to stratify the air and helps limit thermal convection and icing on the sample. Icing on the sample exposed surface has a potential to increase damping artificially by creating friction between the ice crystals formed.
For stiff samples, weights are clamped at the free end to reduce the bending oscillation frequency and so limit the air viscous damping. All samples were set to have a resonance frequency between 10 and 30 Hz.
The samples are excited by loading up elastic energy, and releasing this energy suddenly to measure vibration decay. An accelerometer placed on the sample free-end records the acceleration amplitude. The accelerotmeter acquisition is set to 500 Hz, an order of magnitude above the resonnace frequency. Measurements are made from an acceleration of 2g (19.62 m/s²) down and damping ratio are calculated across as many periods as possible.
When tested at 77K, sample are immersed in LN2 until thermal equilibrium is established and then promptly put upright and excited. Some temperature uncertainty stems from the time needed to mount the sample and excite it – although this was done fast and results were usually repeatable - and some additional uncertainty come from the higher damping of cold and dense air and limited amount of freezing on the sample surface.

*2.2 Data processing*
An example of acceleration decay from the titanium sample is depicted on Figure 1.

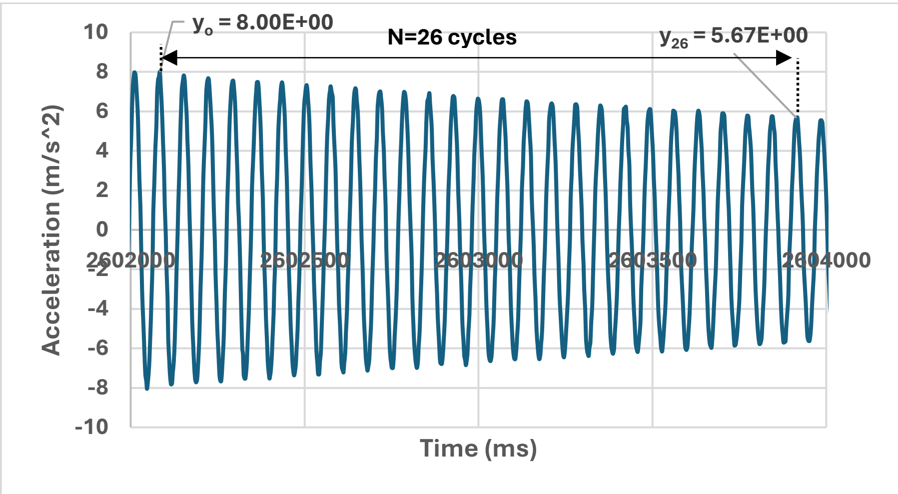


*Figure 1 Acceleration decay from the vibration of the titanium alloy TiAl4V rod – resonance @14.36 Hz*

A fast fourier transform is used to determine the precise resonance frequency, here 14.36 Hz.
As described in Ref.[3] (Eq. 23), the damping ratio can be determined :

$$\xi = \frac{C}{C_0} = \frac{\ln(y_0/y_N)}{\sqrt{(2\pi N)^2 + \ln(y_0/y_N)^{\,2}}}$$

In this case, using values from Fig. 1 :

$$\xi = \frac{\ln(8.00/5.67)}{\sqrt{(2\pi.26)^2 + \ln(8.00/5.67)^{\,2}}} = 0.0021\ (0.21\%)$$

## 3. On the significance of the damping ratio $\xi$

The analysis of a 1D harmonic oscillator driven by a sinusoidal displacement excitation $x_a(t) = Asin(\omega t)$ gives Ref. [3,4,5] :

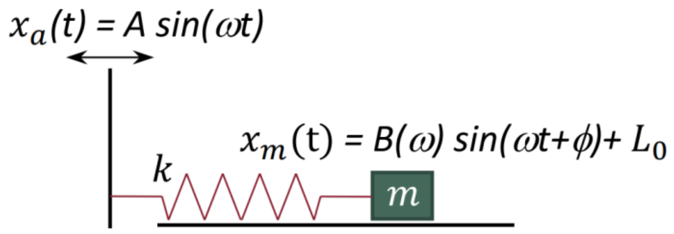


*Figure 2 : 1D harmonic oscillator driven by a displacement – Figure from [5]*

$$|B(\omega)| = \frac{|A|}{\sqrt{\left(1-\left(\frac{\omega}{\omega_0}\right)^2\right)^2 + 4\xi^2\left(\frac{\omega}{\omega_0}\right)^2}}$$

Note that the damping ratio also shifts the effective resonance frequency $\omega_{res}$ from the undamped resonance frequency $\omega_0$ as such:

$$\omega_{res} = \omega_0\sqrt{1-2\xi^2}$$

So, at the damped resonance frequency $\omega_{res}$:

$$|B(\omega_{res})| = \frac{|A|}{2\xi\sqrt{1-\xi^2}}$$

In practice, $\xi^2 \ll 1$ ($\rightarrow \sqrt{1-\xi^2} \approx 1$) and so the vibration amplification at resonance $\omega_{res}$:

$$\frac{|B(\omega)|}{|A|} \propto \frac{1}{2\xi}$$

From this, to accurately predict the amplification when a structure resonance is excited, the knowledge of the damping ratio $\xi$ is required, as the resonant displacement amplitude in inversely proportional to $\xi$.

In some applications, the integrated motion amplification over a frequency range is more useful than the peak resonant amplitude at given frequency. For example, this is true for the evaluation of accelerators components stability under a broadband excitation.

A discussion of getting the integrated amplification factor is offered in annex 1, the dependence of the integrated motion amplification is shown to be:

$$\int \frac{|B(\omega)|}{|A|} df \propto \frac{1}{\xi^{0.23}} \text{ (approximately)}$$

For a consistent broadband excitation.

## 3. Test results and discussions

*3.1 Results*

Figure 3 summarizes the results of the testing described in section 2.
The damping ratio is represented as blue bars for 293K testing and orange bars for ~77 K testing. The error range represent the difference between the average value reported and the extreme value obtained in the multiple testing attempts for each sample.

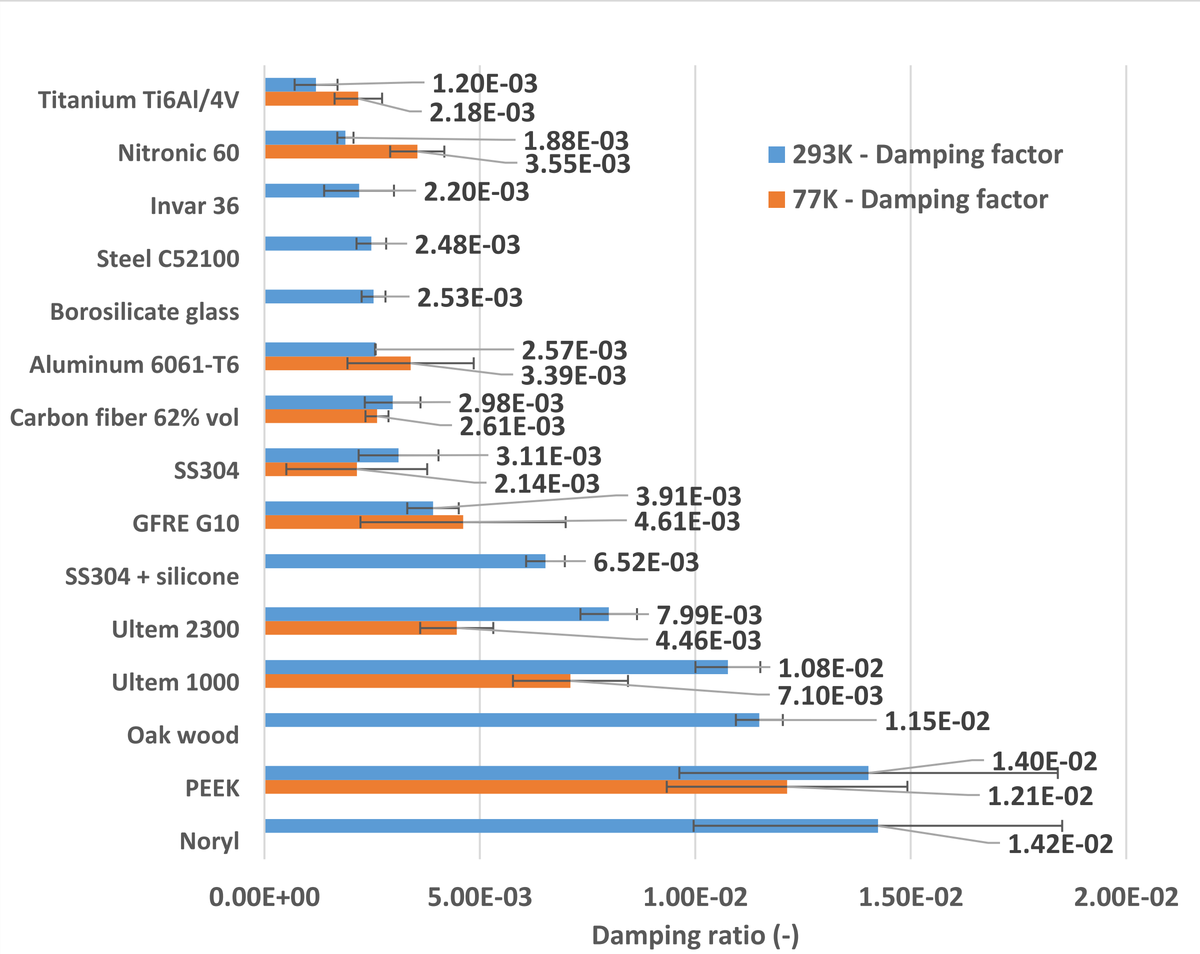


*Figure 3 Structural damping ratio for various materials in air – samples ranked in increasing damping ratio at 293K*

*3.2 Discussion of the result*

The data obtained are generally consistent with data available in the literature [6][7].
From Fig.3 metals and glass show the lowest damping ratio, followed by composite materials, wood and plastics. Available material certificates are available in appendix 2.
Short glass fibers in ULTEM tend to decrease the damping ratio (ULTEM 2300 has 30% short glass fibers compared to the unfilled 1000).
The damping ratio of plastics decreases markedly at 77K (Ultem 1000, 2300, PEEK). This is consistent with results previously reported in [8]. However, this effect is much less present in the long fiber-composite samples tested - G10 and carbon fiber CFRE - where the damping ratio change is relatively small between 293 K and 77 K.
Metals also show relatively small variation. While Ti-6Al-4V, Nitronic and Al 6061-T6 seems to show a minor increase in damping at cold, stainless-steel 304 shows a slight decrease.

However, with the relatively low values of damping ratio of metals, it is hard to rule out an effect of higher viscous damping due to the dense cold air around the sample or local freezing on the sample surface at cold temperature. To refine these results further, one should aim to use a setup under vacuum as discussed later in this report.

*3.3 Applying an elastomer coating to improve damping?*

Elastomers are well-known to have a superior damping coefficient [7].
In order to evaluate the effect of applying an elastomer coating on the surface of a metallic sample, the stainless-steel SS304 sample was coated with a thin layer of "self-levelling" silicone (Dow Corning 734®). The sample was then wiped immediately after silicone application to obtain a very thin and consistent coating thickness.
Testing at room-temperature showed an interesting increase in damping ratio of the stainless-steel sample from 3.11E-3 to 6.52E-3, about a factor 2x.
Based on this, applying an elastomer coating to the deforming areas of a resonating structure could help reduce the resonant amplitude by a factor 2x at least. To push this possibility further, more testing should be done to determine the best elastomer type and thickness to increase damping as needed.
The same sample tested at 77K also showed a significant damping ratio increases on the first attempt, but this quickly degraded over the next attempts until the damping ratio became equal to regular stainless steel damping ratio at 77K. This is suspected to be because of elastomer layer delamination which was visible on the sample surface after cryogenic testing.

*3.3 Suggestions for future setup improvement*

As previously discussed in section 2, steps were taken to minimize the effect or air viscous damping and clamp frictional damping on the results, but some influence is unavoidable.
Ref. [8] describe a similar setup used in air and under vacuum and reports no significant difference between air and vacuum testing.
To try to estimate the effect of air on the results reported, the lowest structural damping coefficient measured with this setup was 9E-4. So, it can be concluded that the effect of air viscous damping and frictional damping combined, is less than 9E-4 in our setup configuration (probably significantly less- given that the material structural damping is also contributing).

To fully separate structural damping from viscous air drag damping effect, for example for the accurate design of accelerators supporting structures in vacuum (magnet cryostat supports -see Ref. [6] or SRF cavities supports) it would be best to design a testing setup under vacuum.
An example of simple and effective setup is described in Ref. [8] where the sample is enclosed in a vacuum test chamber submerged in cryogen. The sample excitation can be done through an electromagnet. Using thin blades samples instead of a rod will help simplify and improve the fixed-end clamping – where any possible friction with the sample is to be avoided – and avoid exciting resonance mode in directions other than the direction of interest.

## Conclusion

A relatively simple test setup was used to estimate structural damping values for different materials. The results obtained match relatively well with litterature data and can be used to approximate the resonnance amplitude of vibrating structures.

## References

[1] A. Seryi, “Ground Motion and Vibration Issues for Accelerators”, in *Proc. PAC'01*, Chicago, IL, USA, Jun. 2001, paper WOAB009, pp. 364-368.

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[3] Casiano, M. J, *Extracting Damping Ratio from Dynamic Data and Numerical Solutions*. NASA, Marshall Space Flight Center, 2016. Print.

[4] Wikipedia – “Harmonic oscillator” - https://en.wikipedia.org/wiki/Harmonic_oscillator - Accessed 10/2025

[5] P. Podobedov – ESR Magnet vibrational specifications for dynamic orbit stability at the IP – BNL Tech Note EIC-ADD-TN-022

[6] Structural damping properties of mechanical systems – JPE innovation - structural-damping-properties-mechanical-systems - Accessed October 2025

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[8] L.J. Wolf, J.H. Sondericker, and W.A. DeVito, "Elastic Moduli of Ultem and Noryl at Cryogenic Temperatures Using Vibrating Beam Specimens," AD/RHIC/RD-21, Brookhaven National Laboratory, June 1990.

[9] F. Micolon and J. Greene, "Understanding the RHIC triplet magnet vibrations in preparation for EIC", in Proc. NAPAC2025, Sacramento, CA, USA, Aug. 2025, pp. 880-883. doi:10.18429/JACoW-NAPAC2025-WEP095

## Annex 1 – Evolution of the broadband amplification factor with damping ratio

As pointed out in the report, the vibration amplification at resonance:

$$\frac{|B(\omega)|}{|A|} \propto \frac{1}{\xi}$$

However, to get the overall impact of the damping ratio on amplification integrated over a range of frequency we can look at the integrated amplification factor from a unit broadband excitation. For example, looking at a unit excitation ($|A| = 1$) from 1 Hz to 100 Hz of a system with a resonance at 50 Hz and varying the damping ratio ($\xi = [0.001;\ 0.005;\ 0.01]$ :

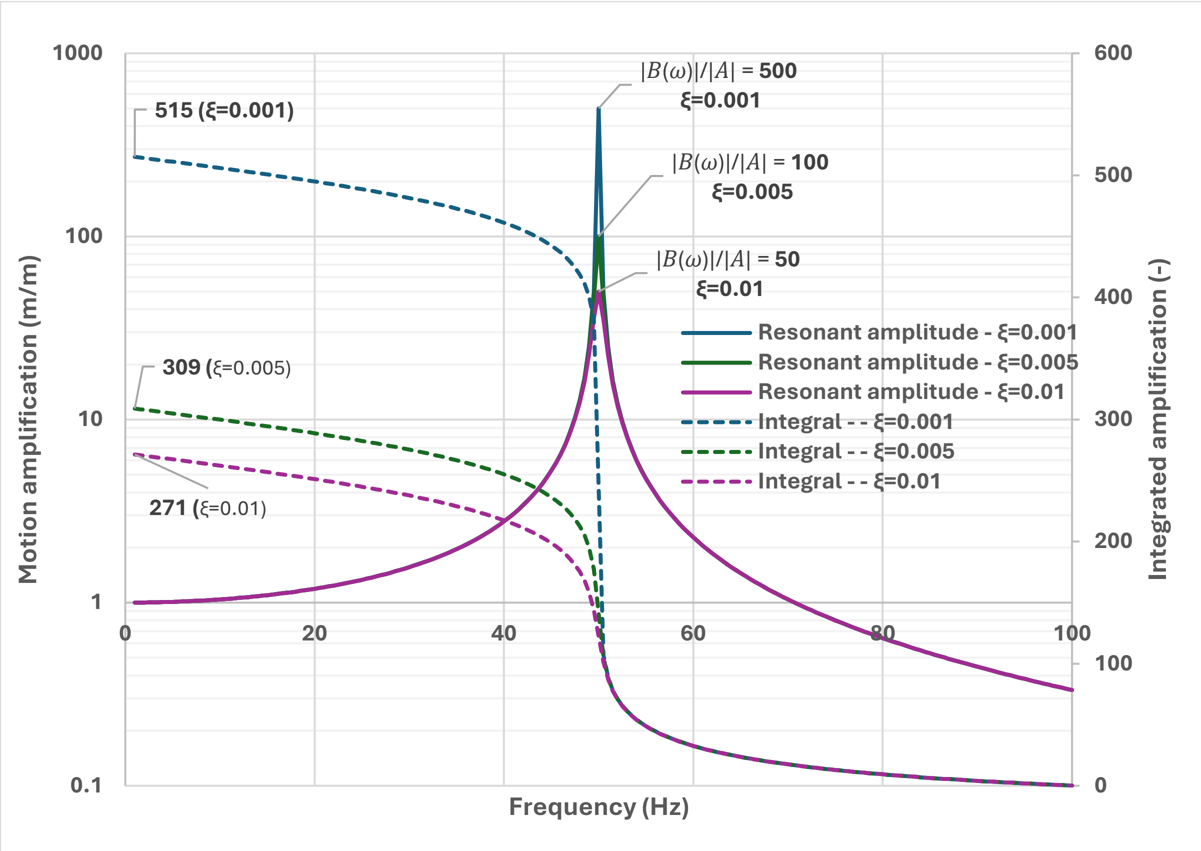


*Figure 4 Amplification factor and integrated amplification from 1 Hz to 100 Hz of a unit base excitation*

Figure 4 shows that the integral of amplified motion from a unit broadband excitation is not linear and tapers off with increasing damping ratio.

Figure 5 shows the plot of $\int_{1\ Hz}^{100\ Hz} \frac{|B(\omega)|}{|A|} df$ against $\xi$ :

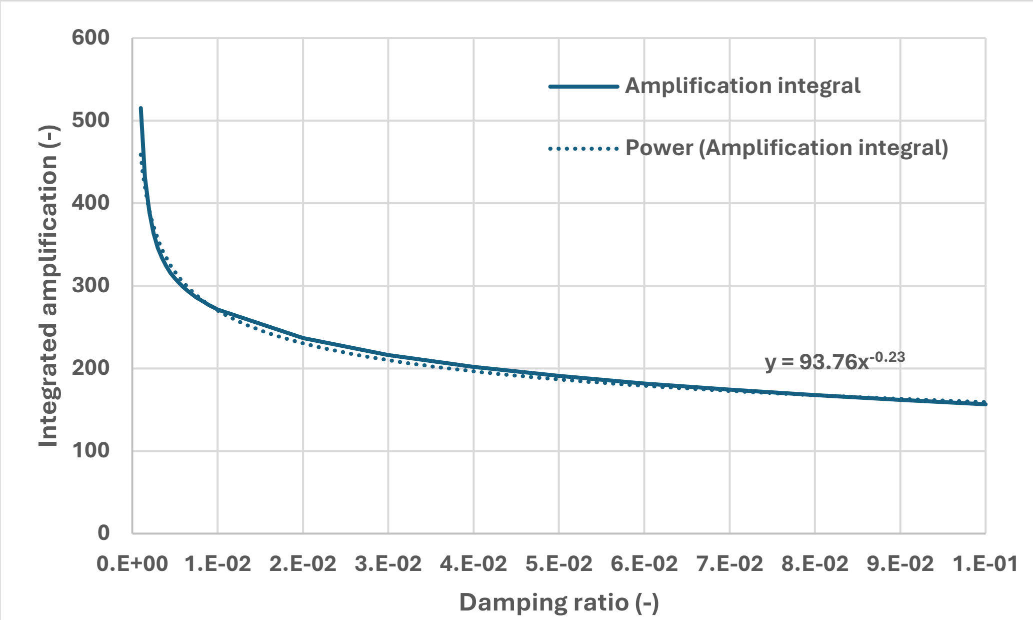


*Figure 5 Integrated amplification from 1 Hz to 100 Hz against damping ratio*

In this range, the interpolation points at a dependence in:

$$\int_{1\ Hz}^{100\ Hz} \frac{|B(\omega)|}{|A|} df \propto \frac{1}{\xi^{0.23}}\ (approximately)$$

For example, in this case, multiplying $\xi$ by a factor 10x decreases the integrated displacement amplification only by a factor x0.59 (41% reduction in integrated displacement).

Indeed, it is obvious when looking at figure 4, that the damping ratio only really affects a very narrow band of frequencies around the resonance frequency, while the amplification at frequencies even slightly away from the exact resonance remain mostly unaffected.

*Note: the limit on significance of this simplified analysis is that ground motion is usually not a consistent broadband excitation – instead ground motion amplitude decreases sharply with increasing frequencies.*

## Annex 2 – Material certificates for samples used

### Ti-6Al-4V sample

Perryman company
625 Technology Dr., Coal Center, PA 15423
phone: 724-746-9390 fax: 724-746-9392

**CERTIFICATE OF TEST**
**For TITANIUM INGOT**

SHIP TO
**Perryman Company**
**213 Vandale Drive**
**Houston, PA 15342**

WORK ORDER **055633**
HEAT NUMBER **PV10144**

QUANTITY **12460 LBS**
PCS **1**

DESCRIPTION **FORM: Ingot, Grade: Ti6Al/4V, Size: 30**

SPECIFICATION CAPABILITY
**P-101 Rev 6**

**Chemistry (WT%) Top**

| O | N | C | Fe | Al | V | Si | Cu | Pd | Y | H | B | Ru |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| .15 | .010 | .023 | .22 | 6.08 | 3.97 | .019 | <.004 | <.005 | <.005 | .0006 | <.003 | <.005 |

**Chemistry (WT%) Bottom**

| O | N | C | Fe | Al | V | Si | Cu | Pd | Y | H | B | Ru |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| .17 | .011 | .018 | .16 | 6.19 | 3.81 | .012 | <.004 | <.005 | <.005 | .0005 | <.003 | <.005 |

**Comments**

Melting Process:
EBCHR-VAR

Calculated Beta Transus T/B:
1814F/1829F

Calculated Beta Transus T/B C:
990C/998C

Residual Elements, each < .05%
Residual Elements, total < .20%
Balance Titanium.
Melted in the United States of America.
The material is free of radioactive and mercury contamination.
Oxygen/Nitrogen tested in accordance with ASTM E1409.
Carbon tested in accordance with ASTM E1941.
Hydrogen tested in accordance with ASTM E1447.
B tested in accordance with ASTM E2994.
Metallics Tested By XRF in accordance with ASTM E539.
**Elements not required by specification are included in Others(each) and Others(Total)**

Nadcap ACCREDITED
Materials Testing Laboratory

This material conforms to the chemistry and quality system requirements of the specifications and/or Purchase Order referenced. The results relate only to the lot tested and the results are contained in the records of Perryman Company.
The certificate of test cannot be reproduced except in full without the written approval of the laboratory, and the recording of false, fictitious, or fraudulent statements or entries on this document may be punished as a felony under federal law.

**Michael DeAngelis**
**Senior Laboratory Technician**
Date Printed: 12/12/2022

Page 1 of 1

**Nitronic 60 sample**

**CERTIFICATE OF TESTS** **ABNAHMEPRUEFZEUGNIS** **CERTIFICAT DE CONTROLE**

Certification ID:001306630

CARPENTER

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07/19/23

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|---|---|---|---|
| REFER TO PAGE 1 | W41346 | SEE PG 1 | SEE PG 1 |

HEAT NUMBER / SCHMELZE-NR. / N° DE COULEE : 592746

PRODUCT DESCRIPTION: GALL-TOUGH PLUS STAINLESS/UNS S21800 ANNEALED GROUND
--------------------

SPECIFICATION: ASTM A194/A194M-20A GRADE 8S (CHEM.ONLY)
-------------- ASTM A484/A484M-21 A484 TABLE 7 (11/01/21)
ASTM A193/A193M-20 GR.B8S CL. 1C & 1D
ASME SA-479/SA-479M UNS S21800 2019 EDITION
ASME-SA276 UNS S21800 2019 EDITION
ASTM-A479/A479M-21 S21800 (11/01/21)
ASTM A580/A580M-18 "CHEMISTRY ONLY"
ASTM A276/A276M-17 UNS S20162/S21800
AMS 2750 REV E (07/01/12)
GE S-SPEC-35 (S-400) (02/28/21)
AMS 5848 REV E (07/ /18)
ASTM F899-20 UNS S21800
GE S-SPEC-1 (S-1000) (04/01/21)
ASTM-A314-19 UNS S21800
10001517 GALL-TO BAR REV 0 (03/16/21)

SIZE 0.250000 IN.( 6.35 MM) RD BAR

HEAT CHEMISTRY(WT%): (TEST METHOD IS SHOWN IN PARENTHESIS)

| C (COM) | MN(XRF) | SI(XRF) | P (XRF) | S (COM) | CR(XRF) |
|---|---|---|---|---|---|
| 0.09 | 7.46 | 3.73 | 0.021 | 0.027 | 17.64 |

| NI(XRF) | MO(XRF) | CU(XRF) | CO(XRF) | N (FUS) |
|---|---|---|---|---|
| 8.35 | 0.56 | 0.13 | 0.06 | 0.16 |

THIS MATERIAL HAS BEEN MANUFACTURED, SAMPLED, TESTED AND INSPECTED IN ACCORDANCE WITH THE SPECIFICATION AND ANY SUPPLEMENTARY REQUIREMENTS DESIGNATED BY THE PURCHASE ORDER OR CONTRACT AND WAS FOUND TO MEET THOSE REQUIREMENTS.
GEAG SUPPLIER CODE - 21100/CARPENTER, T9406/ATHENS, 51904/LATROBE
INTERGRANULAR CORROSION TESTED TO ASTM-A262, PRACTICE E - ACCEPTABLE.
***AS RECEIVED*** (DUAL)
ANNEALED MICROSTRUCTURE FREE FROM CONTINUOUS GRAIN BOUNDARY CARBIDE PRECIPITATION (NETWORK).
COUNTRY OF ORIGIN: USA
MATERIAL SUPPLIED CONFORMS TO THE TECHNICAL REQUIREMENTS OF THIS SPECIFICATION.
MATERIAL IS COMPLIANT TO 2015/863/EU (ROHS3) DIRECTIVE.
THIS MATERIAL CONTAINS NO WELDS OR SPLICES

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|---|---|---|---|
| REFER TO PAGE 1 | W41346 | SEE PG 1 | SEE PG 1 |

HEAT NUMBER / SCHMELZE-NR. / N° DE COULEE : 592746

THE ITEMS UNDER THIS PURCHASE ORDER CONTAIN NO MERCURY OR MERCURY COMPOUNDS AND ARE FREE FROM MERCURY CONTAMINATION DURING MANUFACTURING AND SECONDARY PROCESSING.
FURNACES WERE CALIBRATED IN ACCORDANCE WITH THE LATEST REVISION OF AMS 2750
THIS HEAT MELTED BY THE ELECTRIC ARC/AOD PROCESSES

MILL HEAT TREATMENT:

| | |
|---|---|
| TYPE | SOLUTION ANNEAL |
| TEMP | 1951F ( 1066C) |
| TIME (BATCH FURNACE) | .50 HOURS |
| QUENCH | WATER |

HARDNESS AS SHIPPED, HBW - 214 (MIDRADIUS)
THE INDENTATION MEASURING DEVICE WAS A TYPE A.
*-->TESTED AT READING

| (T)RANSVERSE (L)ONGITUDINAL | L |
|---|---|
| YIELD STRENGTH, (0.20 %) KSI(MPA) | 72.0( 496) |
| TENSILE STRENGTH, KSI(MPA) | 119.0( 820) |
| ELONGATION IN 1.05", % | 74.0 |
| REDUCTION OF AREA, % | 72.0 |

*-->TESTED AT READING

GRAIN SIZE PER ASTM E112: 5 (KALLINGS NO.2)
*-->TESTED AT READING

HARDNESS AS SHIPPED, HRC - 22 (MIDRADIUS)

*-->TESTED AT READING

CONTINUED ON NEXT PAGE

**Invar 36 sample**

Deutsche Nickel
Rosenweg 15 · 58239 Schwerte · Germany

# Inspection Certificate

EN 10204 - 3.1

**Certificate No: 3434 / 2022 Rev. 1**

DEUTSCHE NICKEL AMERICA

70 Industrial Road
USA - 02864 Cumberland, RI
USA

**Order-No.:**
206504 / 25.07.2022

**Confirmation-No.:**
80162691 / 1

**Material:** Dilaton36

**Mat.-No.:** 1.3912
UNS K 93603

**Form of delivery:** wire

**Dimension:** dia. 6,350 mm
dia. 0.250"

**Specification:** ASTM F 1684-06 (Reapproved 2016)
UNS K 93603
SAE AMS-I-23011C-17 Cl. 7,(chem.only)

**Condition:** cold drawn, annealed, in cut length

**Net Weight:**
503,50 kg
1110,03 lbs

**No. of pieces:**
20 bundles

**Heat-No.:**
52024

## MEASURED VALUES

Melting Composition (mass-%):

| Al | C | Cr | Mg | Mn | Ni | P |
|---|---|---|---|---|---|---|
| <0,01 | 0,01 | 0,04 | <0,002 | 0,30 | 36,1 | <0,003 |

| S | Si | Ti |
|---|---|---|
| 0,004 | 0,10 | <0,005 |

| | |
|---|---|
| Tensile strength [PSI] | 67900 |
| Coefficient of thermal expansion 30 - 150 °C [10exp.-6 / K] | 1,8 |

Cert Rev. 1 by A.Goersch dt. 05/04/2023 (original cert dt. 10/27/2022):
"UNS number corrected"

The material supplied is free from contamination of mercury and has not been weld repaired.
The material was manufactured without the use of ozone-depleting chemicals.
The reported results represent the actual attributes of the material furnished and indicate full compliance with all applicable specification and contract requirements.
The recording of false, fictitious or fraudulent statements or entries on this document may be punished as a felony under Federal Statutes.
DFAR 252-225-7009 Compliant
Country of Origin: Germany

**Steel C52100**

BANNER SERVICE CORPORATION
Providing Comprehensive Bar Solutions

Banner Service Corp
www.bargrind.com
494 E Lies Road
Carol Stream, IL 60188

# Certificate of Compliance

| | | | |
|---|---|---|---|
| Customer Number | C000539 | Customer Name | Castle Metals IL |
| Customer PO | 637232 | Customer Address | 3800 Enterprise Drive Janesville, WI 53546 |
| Customer Part Number | 2500/.2450" E52100 | | |
| Producing Plant | Carol Stream | Ship Date | 06/09/2023 |
| Item Number | C52100 R 0.2500 | Production Order Number | |
| Item Description | CN52R.016- 1/4" RD E52100 .2500/.2450" CF X 144" ASTM.A295 | Sales order | SO-C0072625 |
| | | Heat Number | 418531 |
| | | Quantity in lb | 820.00 |
| | | Quantity in Pounds | 820.00 |

## Heat Attributes

| Heat Attribute Description | Result | Heat Attribute Description | Result |
|---|---|---|---|
| **Physical** | | **Chemical** | |
| OD for Round, Thickness for Flat | 0.2500 | Chromium | 1.4200 |
| Grade | C52100 | Copper | 0.0900 |
| Length | 144.0000 | Manganese | 0.2900 |
| Shape | R | Molybdenum | 0.0500 |
| **Chemical** | | Phosphorous | 0.0040 |
| Tin | 0.0100 | Sulfur | 0.0050 |
| Titanium | 0.0010 | Silicon | 0.2500 |
| Hydrogen | 0.0001 | Calcium | 0.0002 |
| Antimony | 0.0010 | **Mechanical** | |
| Aluminum | 0.0380 | Cast Method | INGOT |
| Nickel | 0.0800 | Rolling/Processing Source 1 | FN STEEL-NETHERLANDS |
| Oxygen | 0.0003 | Rolling/Processing Source 2 | SULLIVAN STEEL-US |
| Lead | 0.0010 | Annealed | Y |
| Arsenic | 0.0100 | Grain Size | 8.0000 |
| Aluminum | 0.0380 | Melt Source/Location | OVAKO-SWEDEN |
| Carbon | 0.9900 | UltimateTensile(KSI) | 90.0680 |

MERCURY FREE

Unless noted, this material meets RoHS compliance, REACH compliance, and Conflict Minerals Restrictions.

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David Hallin, Quality Manager

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**Aluminum 6061-T6**

KAISER ALUMINUM
FABRICATED PRODUCTS

Tennalum
309 Industrial Drive
Jackson, TN 38301
731-423-2811

TENNALUM PREFERRED SUPPLIER — MADE IN USA

## CERTIFIED TEST REPORT

http://Online.KaiserAluminum.com

| CUSTOMER PO NUMBER: | CUSTOMER PART NUMBER: | PRODUCT DESCRIPTION: |
|---|---|---|
| 560929-1 | 7891 | Cold Finished Round |

| KAISER ORDER NUMBER: | LINE ITEM: | SHIP DATE: | ALLOY: | TEMPER: | |
|---|---|---|---|---|---|
| 741256 | 1 | 02/22/2021 | 6061 | T6 | |
| **WEIGHT SHIPPED:** | **QUANTITY:** | **B/L NUMBER:** | **DIAM/DAF/THKNS:** | **WIDTH:** | **LENGTH:** |
| 1085 lbs. | 1576 pcs. | 45813 | 0.250 in. | 0.000 in. | 144.0 in. |

| SHIP TO: | SOLD TO: |
|---|---|
| A M Castle & Co<br>3800 Enterprise Drive<br>Janesville, WI 53546 USA | A M Castle & Co<br>1420 Kensington Road<br>Suite 220<br>Oak Brook , IL 60523 USA |

Test Code: 1000 AC

## Actual Physical Properties

| Lot Number | LONG. UTS ksi | LONG. YTS ksi | LONG. ELONG. % |
|---|---|---|---|
| 10079543 | 50.9 | 48.5 | 14.0 |
| | 51.6 | 49.5 | 11.5 |

## Chemical Composition, WT. % (Aluminum Remainder)

| | Si | Fe | Cu | Mn | Mg | Cr | Zn | Ti | OTHERS EACH | OTHERS TOTAL | Lot |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Actual | 0.74 | 0.4 | 0.33 | 0.07 | 1.0 | 0.14 | 0.12 | 0.03 | | | 10079543 |
| Max | 0.8 | 0.7 | 0.40 | 0.15 | 1.2 | 0.35 | 0.25 | 0.15 | 0.05 | 0.15 | |
| Min | 0.40 | | 0.15 | | 0.8 | 0.04 | | | | | |

## Specifications

ISO 9001,ASTMB211-19,AMS4117L,AMS-QQ-A-225/8A, A96061_01_R20 w exceptions

**CERTIFICATION**

Kaiser Aluminum Fabricated Products, LLC ("Kaiser") hereby certifies that the metal shipped under this order has been inspected and tested and found in conformance with the applicable specifications forming a part of the description set forth in Kaiser's sales acknowledgement form. Any warranty is limited to that shown on Kaiser's general terms and conditions of sale. Test reports are on file, subject to examination.

John Rennekamp, Quality Manager

Plant Serial: 282834
Kaiser Order Number: 741256
Line Item: 1

## Carbon fiber sample

| | |
|---|---|
| Length | 12" |
| Materials | Standard Modulus Carbon |
| OD | 0.25 |
| Outside Dimension | 0.25" |
| Shape | Round Rod |
| Weight | 0.246 lb |

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# Technical Data

# Minimum Properties:

Tensile Strength: 250 ksi | 1.72 GPa
Tensile Modulus: 20 msi | 138 GPa
Ultimate Shear Strength: 6.0 ksi | 41.3 Mpa
Ultimate Tensile Strain: 1.5%
Flexural Strength: 265 ksi | 1.83GPa
Flexural Modulus: 19 msi | 131 GPa
Coefficient of Thermal Expansion: -0.1 ppm/ºF | -0.2ppm/ ºC
Density: 0.054lbs/in³ | 1.5g/cm³
Fiber Volume: 62%
Glass Transition Temperature: 100ºC
Matrix Material: Bisphenol Epoxy Vinyl Ester

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# Tolerances

Diameter Tolerance: +/- 0.007"

**Ultem 2300 sample**

Ensinger

*Declaration of Compliance According to EN 10204 – 2.1*

| | | | |
|---|---|---|---|
| **Customer** | CURBELL PLASTICS INC | | |
| **Customer Location** | ROCHESTER, NY 14624 | **Ensinger Order #** | 929638 |
| **Customer Order #** | 4500565058 | **Order Line #** | 5 |
| **Certificate** | AZE933 | **Issued** | 03/19/2025 |

***Ensinger, Inc. certifies the material shipped is the following***

| | | | |
|---|---|---|---|
| **Trade Name** | TECAPEI™GF30 | **Size / Shape** | 0.25" ROD |
| **Color** | NATURAL | **Nominal Length** | 120.0000" |
| **Material** | GF POLYETHERIMIDE (PEI) | **Nominal Width** | N/A |
| **Production Lot(s)** | 424127 | **Quantity** | 10.0000 FT |
| **Resin Lot(s)** | 1002402748 | **Country of Origin** | USA |
| **Base Resin** | Ultem™ 2300 Series | **Manufacture Date** | May 2022 |

**Ensinger, Inc. certifies typical production lots of the above identified material have been found to comply with the following Specifications and/or Compliances**

| | |
|---|---|
| **Base Resin Spec** | ASTM D5205-24 PEI0110G30A96299 159 MPa 224 MPa 208C |
| **Shape Spec** | ASTM D7293-19 S-PEI0213 |
| **Resin Agency Compliances** | Ref. UL File #E121562 for Resin & Flammability<br>FDA 21 CFR 177.1595 |
| **Prop 65** | WARNING! This product contains Prop 65 listed substances. Contact compliance@ensingerusa.com for a complete declaration. |
| **Customer Compliances** | |
| **Comments** | Every batch of material is not tested. If additional testing is required, it must be requested at time of order.<br>Reported resin lot is representative of the raw material used to manufacture this product. |

Ronald Woolley
Ronald Woolley
Quality Assurance

**Production Lot(s)** 424127
**Resin Lot(s)** 1002402748

Ensinger, Inc., 365 Meadowlands Boulevard, Washington, Pennsylvania 15301
Telephone: (724) 746-6050 FAX: (724) 746-9209
**Ensinger, Inc. is registered to ISO 9001:2015**