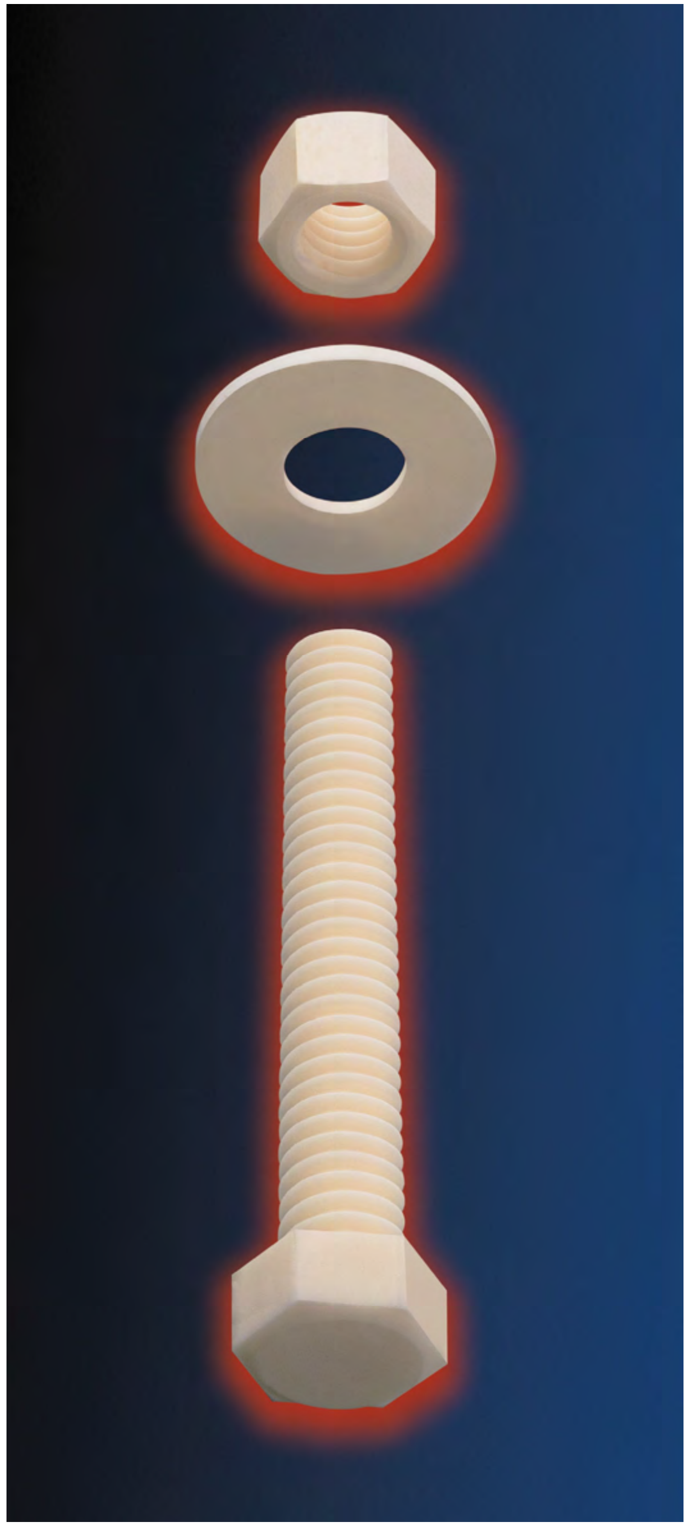
Ceramco, Inc.

Independent Test Data



Mechanical Properties of Ceramco's Solid Ceramic Fasteners

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2020 02

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Mechanical Properties of Certain Ceramic Fasteners

Introduction

Ceramic materials excel where metallic or plastic substitutes simply cannot provide the necessary performance. High wear situations, electrical or thermal insulating applications, corrosive environments, or instances where magnetism, biocompatibility, or outgassing are concerns for many cutting-edge fields. As the extreme performance demands of oil and gas extraction, chemical detection, or deep space exploration (to name a few) go un-met, engineers and designers are turning to ceramic materials to address the performance gaps. Ceramco's line of stock solid ceramic fasteners are the coupling solution when the standard falls short.

Ceramco's solid ceramic fasteners continue to generate considerable interest since they were offered commercially in 1990. With increased interest and exposure has come an increasing desire for mechanical properties (such as recommended installation or service torque and tensile strength) from customers seeking to utilize these fasteners in their applications. To better understand the capabilities of our products and meet the demands and requests of our customers who are becoming more technically advanced in aggregate, Ceramco has obtained unbiased, third-party data based on industry standard test methodologies. As testing continues, these data will help drive and guide material and process development within the company and expand our product offerings.

Additional preliminary research and prototyping of Ceramic Matrix Composites (CMCs) and Zirconia Toughened Alumina (ZTA) fasteners has already begun, and a new line of ZTA fasteners will be launched in 2020.

Sampling

An initial 800 piece lot of high purity alumina (99.8% Al_2O_3) fasteners was submitted to an independent laboratory to begin testing, with supplementary lots of varied materials (stabilized ZrO_2) and sizes forwarded thereafter. Submitted lots were evenly divided for destructive Tensile and Torsion testing. Sizes and compositions tested to-date are in Table A.

Size	Length	Type	Mat'l. Tested
5/16"-18	3.000"	Hex Bolt	Alumina
1/4"-20	3.125"	Hex Bolt	Alumina/Zirconia
#10-32	2.063"	SHCS	Alumina
#8-32	2.000"	Hex Bolt	Alumina
#6-32	1.500"	Hex Bolt	Alumina
#4-40	1.063"	Hex Bolt	Alumina
M5 X .8	40mm	Hex Bolt	Alumina/Zirconia
M4 X .7	40mm	Hex Bolt	Alumina/Zirconia
M3 X .5	25mm	PHP	Alumina
M2 X .4	10mm	Hex Bolt	Alumina

Table A

Test Method

Engineered ceramics of the high-purity oxide type have high relative hardness and correspondingly low ductility. As such, test results would show no definable separation between proportional and elastic limits, thereby limiting the utility of NDT. Acknowledging these inherent issues from the outset, Ceramco elected that all testing would be destructive.

Testing was conducted per the methodologies outlined by ASTM F606/F606M Standard Test Methods for Determining the Mechanical Properties of Externally and Internally Threaded Fasteners, Washers, Direct Tension Indicators and Rivets.

Tested sizes were selected based on historic customer demand (though length was determined by the test facility based on fixturing needs) and tailored to ensure that the range of tested sizes would allow for reasonable extrapolation for uncommon and non-standard sizes. Test specimens were randomly selected from current and former production lots, packaged to maintain randomization, labeled for size and material and delivered to the test facility.

Test Summary

In general, obtained data well represented the normalcy and distribution anticipated of engineered ceramic materials tested in tensile and torsional modes. Similarly, the obtained data have a high degree of conformance with data obtained via internal testing, confirming the validity of historically accepted values and the verification practices employed by Ceramco for both production materials.

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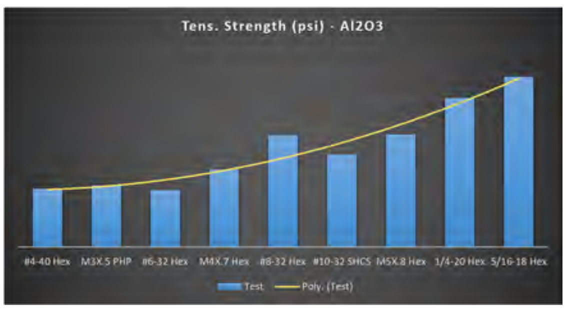
Results: Tensile

Tensile strength is not often requested by potential customers since ceramics are not traditionally used for their performance in this area. However, tensile strength is one of the most commonly used measures of material performance which will allow for more appropriate design and use if known, or if retrofitting an existing assembly using other materials. Further, understanding the tensile strength of ceramic fasteners will help Ceramco continue to innovate by establishing a baseline against which new or novel materials may be measured.

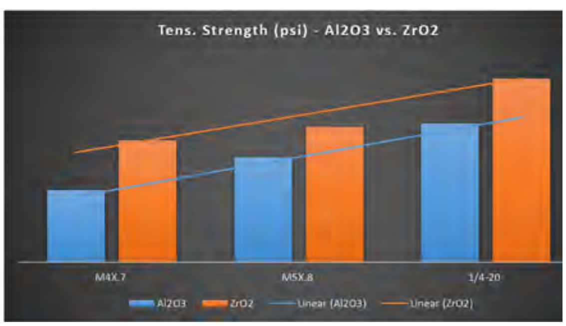
As noted above, the test facility recorded and reported the maximum values obtained during destructive testing.

Being sufficient for most ceramic fastener purposes, the high purity alumina (A998) fasteners were tested and analyzed first, see table B.

Making use of zirconia (ZrO_2) in the manufacture of ceramic fasteners allows Ceramco to enhance fastener performance for more rigorous and/or unique applications. See table B for stabilized zirconia fasteners' tensile strength.



Graph 1



Graph 2

Size	High Purity Alumina	|	High Purity Zirconia
	Proof (lbs)	|	Proof (lbs)
#0-80	18.06	|	- - -
M2 X 0.4	26.86	|	38.17
#2-56	28.15	|	39.97
#4-40	37.01	|	52.34
#5-40	43.7	|	61.69
M3 X 0.5	44.94	|	63.42
#6-32	46.58	|	65.71
#8-32	59.91	|	84.33
M4 X 0.7	60.81	|	85.55
#10-24	66.86	|	94.04
#10-32	73.3	|	103.02
M5 X 0.8	78.89	|	110.86
1/4-20	92.6	|	129.99
M6 X 1.0	94.76	|	132.99
5/16-18	121.33	|	- - -
M8 X 1.25	129.82	|	- - -
3/8-16	149.13	|	- - -

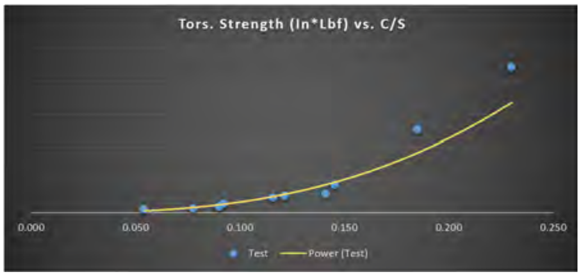
Table B

For customers seeking to load ceramic fasteners in a purely tensile mode, or whose application may induce tensile loading during use or operation, Ceramco has delineated the Proof Strengths in Table B. Customers should ensure that their application does not exceed the values listed.

Results: Torsion

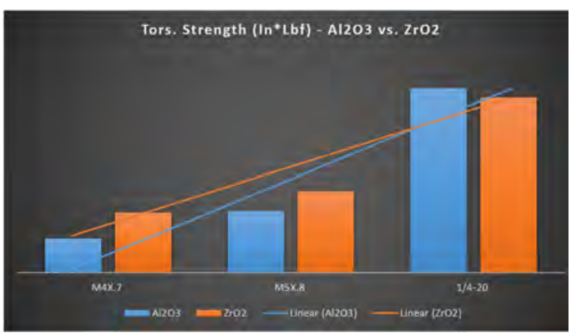
As mentioned above, monolithic ceramic materials are inherently brittle. This fact alone makes proper installation torque critical to the function and utility of a ceramic fastener, so it is of little surprise that torque requirements are chief among fielded fastener-related inquiries at Ceramco. Luckily, torsion is the most tangible and easily measured mechanical property an end-user is likely to encounter while working with fasteners. Established limits allow a customer or end-user to simply set a torque wrench and install the fastener without over-tightening and shearing the head off.

As with tensile testing, all torsional testing was destructive. Recorded torsional data on alumina fasteners displayed good correlation with historic data gathered internal to Ceramco, returning torsional strengths between approximately 0.4 and 40.42 in*Lbf., respective of fastener size.



Graph 3

As with tensile testing, the results from torsional testing showed increased performance in the zirconia fasteners. It should be noted that, while there is an apparent inversion point in the comparison of ZrO_2 versus Al_2O_3 around Ø.230, this is due to a slight over-performance in the ¼"-20 tpi alumina fasteners tested. Further analysis by fractography may help us understand that phenomena, where it is suspected that the same processing conditions but over different cross sections, can affect grain size in the ceramic body. The alumina was perhaps made more optimally at that particular size, but more work is needed to fully explain the anomaly.



Graph 4

Ceramco recommends consistent and progressive loading when applying torque to ceramic fasteners, as erratic or off-axis loading may lead to premature fastener failure. It should also be noted that perpendicularity and parallelism between joined members is crucial to mitigate application of bending moments which can have a deleterious effect on ceramic materials. Ceramco has established the below listed (maximum) service torque values (Table C) for customers whose application(s) may be dependent on specific torque or preload requirements.

Size	High Purity Alumina	High Purity Zirconia
	Svc. Torque (in*Lbf)	Svc. Torque (in*Lbf)
#0-80	0.13	- - -
M2 X 0.4	0.35	0.5
#2-56	0.4	0.56
#4-40	0.5	1.15
#5-40	1.27	1.79
M3 X 0.5	0.98	1.93
#6-32	0.5	2.13
#8-32	1.98	4.24
M4 X 0.7	1.97	5.48
#10-24	4.09	5.76
#10-32	1.95	7.45
M5 X 0.8	4	8.4
1/4-20	13.45	12.31
M6 X 1.0	10.95	15.43
5/16-18	25.74	- - -
M8 X 1.25	27.04	- - -
3/8-16	40.42	- - -

Table C

About Ceramco, Inc.

Ceramco specializes in the production of custom ceramic parts with complex geometries, matching the appropriate manufacturing technique to your order's requirements. Our capabilities include: high and low-pressure injection molding (LPIM & HPIM), MicroPIM and 3D Printing (Additive Manufacturing) for rapid prototyping and in production quantities. Our manufacturing is supported by our own materials formulation, engineering, tooling & machining. We also manufacture and inventory alumina & zirconia bolts, nuts and flat washers, in both metric and SAE sizes and market them via e-commerce. ISO 9001 and ITAR certified. Ceramco, Inc. was founded in 1982 and is located in New Hampshire's Mount Washington Valley.

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