TRELLEBORG SEALING SOLUTIONS

HiMod® Advanced Composite Bearings

ENGINEERING MANUAL

TOGETHER WE SHAPE A SUSTAINABLE FUTURE

Together We Shape a Sustainable Future

Trelleborg Sealing Solutions is one of the world's leading developers, manufacturers and suppliers of precision seals, bearings and custom-molded polymer components.
We collaborate closely with customers to develop unique, innovative solutions to tomorrow's challenges. Utilizing our dedicated product design, material development and testing capabilities, we are a one-stop-shop providing the best in elastomer, silicone, thermoplastic, PTFE and composite technologies for applications in aerospace, automotive, general industrial and healthcare & medical industries.

With over 70 years of experience, we serve as long-term business partners to help our customers bring products to market faster. Through strategically positioned material and product laboratories, specializing in design and applications, Trelleborg Sealing Solutions engineers support customers with design, prototyping, production, testing, installation and quality assurance using state-of-the-art tools. Our ServicePLUS portfolio of value-added services is designed to help customers optimize their business across the entire value chain.

Trelleborg Sealing Solutions brings leading edge technology and an in-depth, experience-based understanding of applications to customers through a global, but local approach. An international network of over 100 facilities worldwide includes over 40 manufacturing sites, more than 60 Customer Solution Centers and 10 R&D centers. Developing and formulating materials in-house, our material database includes over 2,000 proprietary compounds. We fulfill challenging service requirements, supplying standard parts in volume or a single custom-manufactured component, through our integrated logistical support, which effectively delivers over 40,000 sealing products to customers worldwide.

Trelleborg Sealing Solutions facilities are certified according to current market-related quality standards. In addition to the established ISO 9001 standard, our facilities are certified to environmental, health and safety standards, as well as specific customer specifications. These certifications are in many cases prerequisites, allowing us to comply to all market segment requirements.

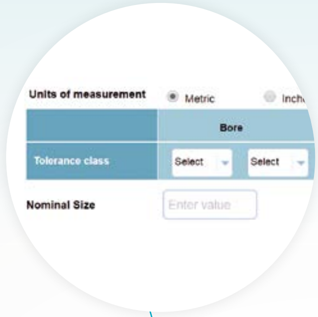
ISO 9001

The information in this catalog is intended for general reference only and not for specific applications. Application limits for pressure, temperature, speed and media are maximum values determined in laboratory conditions. In application, due to operating parameters, maximum values may not be achievable. Customers must satisfy themselves of a product and material's suitability for their individual applications. Any reliance on information is therefore at the user's own risk. In no event will Trelleborg Sealing Solutions be liable for any loss, damage, claim or expense directly or indirectly arising or resulting from the use of any information provided in this catalog. While every effort is made to ensure the accuracy of information contained herewith, Trelleborg Sealing Solutions cannot warrant the accuracy or completeness of information.

Contact your local Customer Solution Center to obtain the best recommendation for a specific application from Trelleborg Sealing Solutions.

Contents

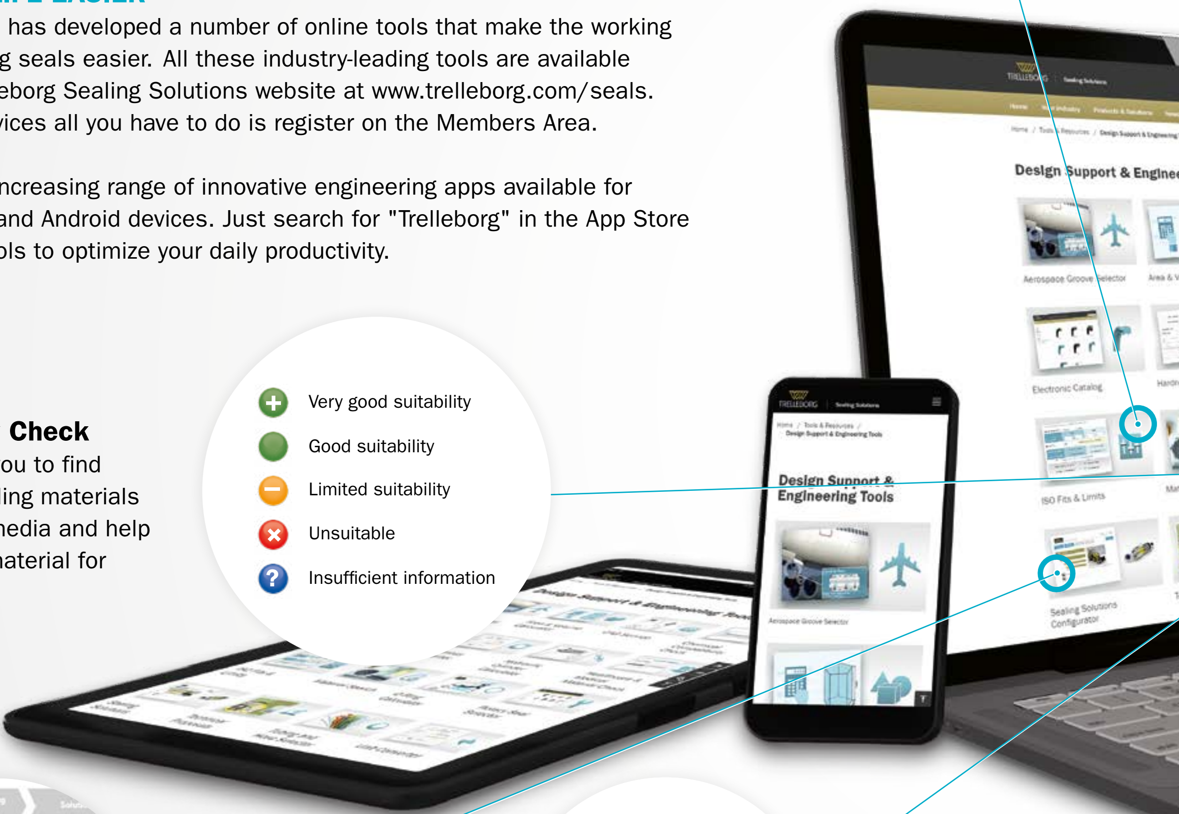
Design Support & Engineering Tools



ONLINE TOOLS MAKE LIFE EASIER

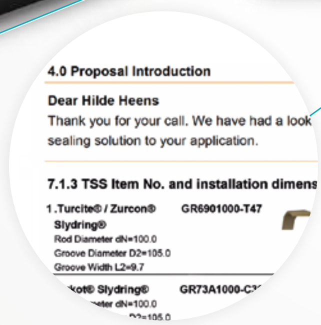
Trelleborg Sealing Solutions has developed a number of online tools that make the working life of an engineer specifying seals easier. All these industry-leading tools are available free-of-charge from the Trelleborg Sealing Solutions website at www.trelleborg.com/seals. To use these advanced services all you have to do is register on the Members Area.

There is also a continually increasing range of innovative engineering apps available for smartphones, both for iOS and Android devices. Just search for "Trelleborg" in the App Store or GooglePlay to find the tools to optimize your daily productivity.



Materials Search and Chemical Compatibility Check

These two programs allow you to find out the compatibility of sealing materials with hundreds of different media and help identify the most suitable material for your application.



Sealing Solutions Configurator

The Sealing Solutions Configurator is the first tool of its kind offered by any seal supplier. It allows engineers to identify a proven sealing solution for their specific application in just four easy steps.

Technical Proposals Online

Enhance your communication with Trelleborg Sealing Solutions with the Technical Proposals Online tool. Instantly access all your proposed solutions anywhere at any time and benefit from quicker dialog with our sealing specialists.

ISO Fits & Tolerances

Our Fits & Tolerances Calculator allows you to easily determine type of fits using the tolerances according to DIN ISO 286. In addition, upon entering the nominal diameter the tool calculates lower and upper limit deviations plus the maximum and minimum interferences dependent on the selected tolerance classes for bore and shaft.

Versatile CAD Service

The CAD download functionality provides thousands of drawings of a wide range of seals. It gives the option of 2- or 3-dimensional files in a range of formats to suit most commonly used CAD systems.

Hydraulic System Calculator

Hydraulic System Calculator helps you design a solution around the cylinder which may involve motor, pump, orifice and pipe calculations. The application is in compliance with ISO 3320, ISO 3321 & ISO 4393.

Rotary Seal Selector

The Rotary Seal Selector allows you to search through the wide range of rotary seals and materials available based on application conditions and offers detailed information on installation and seal capabilities.

O-Ring Calculator

An industry-leading tool, the easy to use O-Ring calculator includes sizing capabilities, compression forces, design parameter recommendations and complete measurements. Results and comments may be printed, shared or filed as PDF.

Discover our design support and engineering tools at **www.trelleborg.com/seals**

Mobile Tools & Apps

We understand the needs of engineers on the go. Check out our latest mobile tools and apps, ranging from an O-Ring calculator to unit and hardness converters. Just search for "Trelleborg" in the App Store or Google Play to find the tools to optimize your daily productivity.

Android App on **Google Play**

MANY MORE APPS available

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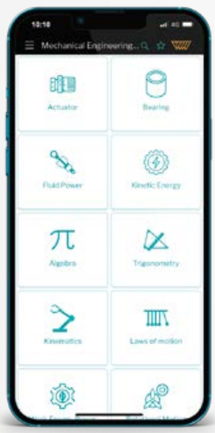
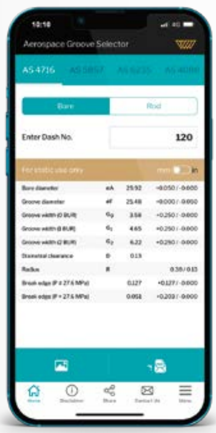
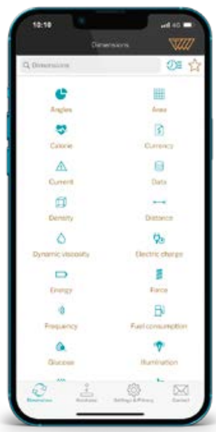
Discover our wide range of mobile tools and apps at **www.trelleborg.com/seals**







ISO Fits & Tolerances

Simply enter the nominal diameter and select the tolerance classes for bore and shaft to find the complete ISO fits definition. It contains all relevant values, including type of fit, with handy graphs to illustrate the classes by bore and shaft. The results of this application are based on DIN ISO 286.

Mechanical Engineering Calculator

A useful app containing over 250 formula calculators in 16 categories, with more being added with every update. Categories include the fields of mathematics, physics and mechanical engineering.

Aerospace Groove Selector

This app covers five of the most important SAE Aerospace groove standards for hydraulic systems, making it quick and easy to find the size of grooves and hardware needed. Includes dimensions for AS4716 Rev B, AS5857 Rev A, AS6235 Rev A, AS4088 Rev E and AS4832 Rev A.

Installation Instructions

Videos demonstrate the best practice methods for installing seals, providing all relevant documentation within the interface. It guides you to successful installation of Radial Oil Seals, Mechanical Face Seals and Turcon® and Zurcon® rod and piston seals.

Converter – Universal

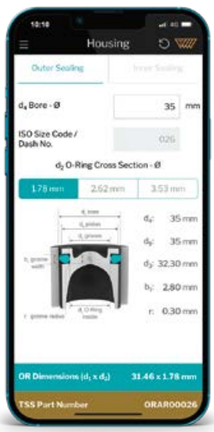
By simply selecting the dimension and entering a value for conversion, the app offers a wide range of engineering and scientific units for each dimension. It also has other useful features like currency conversion, timezone conversion, percentage calculations, a running pace calculator and more.

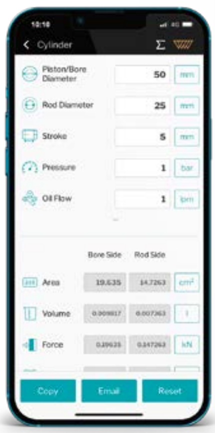
in the groove

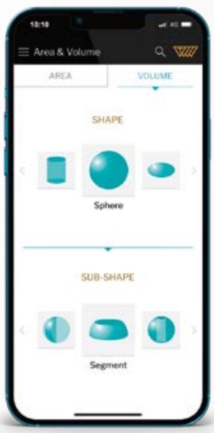
Our *in the groove* magazine provides news, technical and product information on seals, as well as insights into the markets they are used in. The magazine is also available in print and as an interactive PDF.

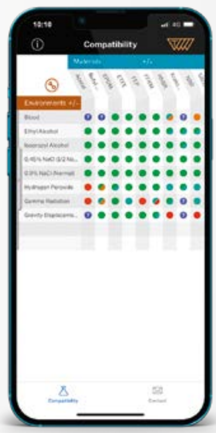
Rotary Seal Selector

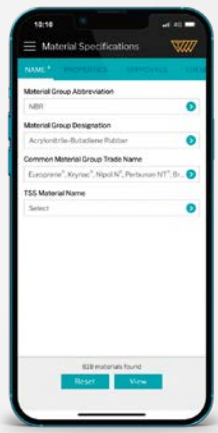
This app is specifically for the selection of rotary seals based on application information, including size, operating parameters and the lubricant used. It also considers installation type and seal function.











O-Ring Selector

When a user enters installation specifications into the O-Ring Selector app, such as the bore or rod/shaft diameter, the app quickly calculates O-Ring and housing dimensions in both metric and inch. Standards covered are ISO 3601-1, NFT 47-502, JIS B 2401 and SMS 1586.

Hydraulic System Calculator

The Hydraulic System Calculator helps you design a solution around the cylinder, which may involve motor, pump, orifice and pipe calculations. The application is in compliance with ISO 3320, ISO 3321 and ISO 4393.

Area and Volume Calculator

Speeds up and simplifies calculating the area and volume of more than 170 geometric shapes. The app supports both metric and inch, and conveniently displays the formulas used. Fill your shape with solids or liquids, choosing from 1500 different materials to calculate the weight.

Healthcare Materials

A quick and easy overview of the compatibility of 34 materials with 35 chemical environments that are commonly encountered in the healthcare and medical industries. Select up to 20 materials and environments at once to produce a chart that rates each material from 'excellent' to 'not recommended'.

Sealing Materials Selector

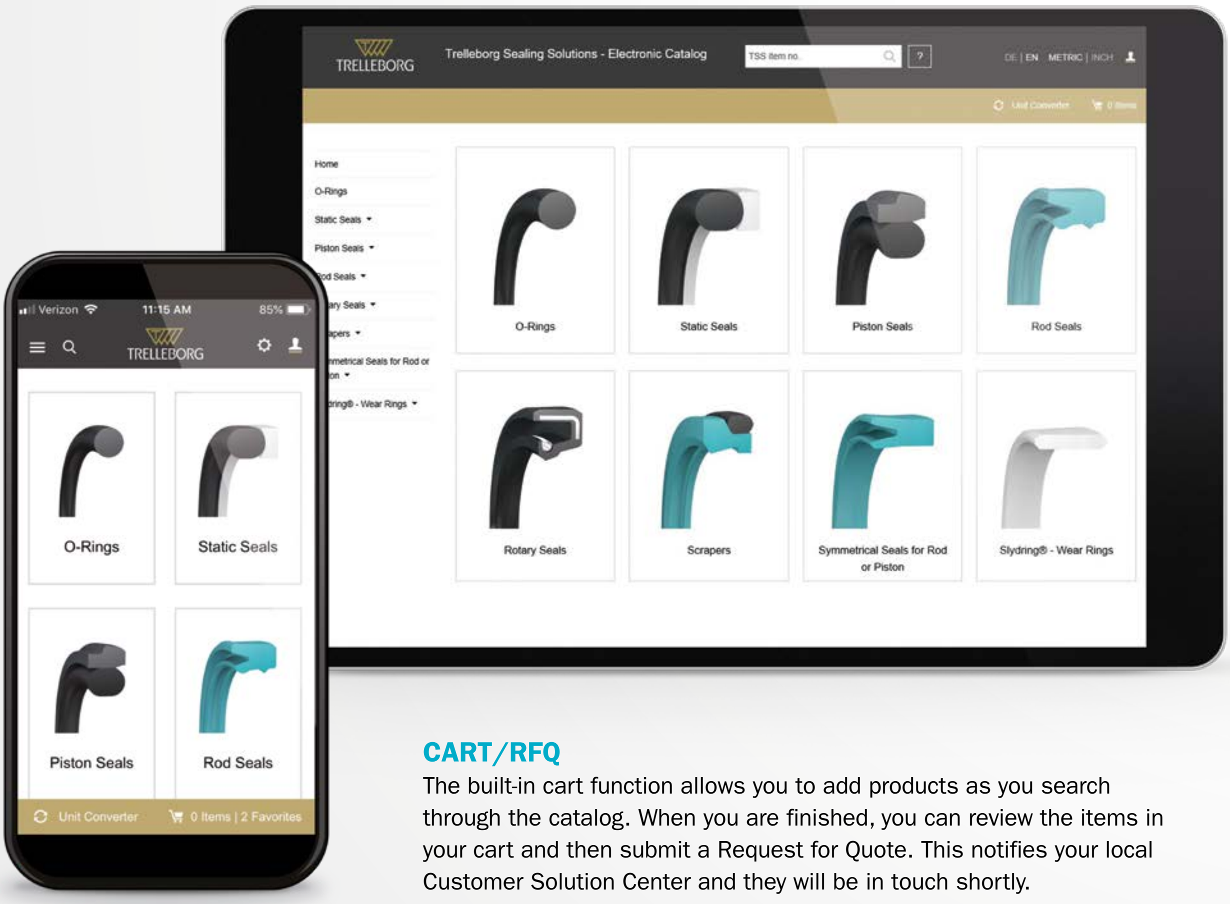
Enter material specifications and required parameters, such as application temperature or hardness, to receive instant material proposals. The app features filters to limit searches based on chemical compatibility, institute approvals and product type. Data sheets can be requested from within the interface.

Electronic Catalog

Discover the Electronic Catalog online as an app or on our website

The Electronic Catalog is a user-friendly service that connects you to the broad range of products Trelleborg Sealing Solutions offers. The products are arranged based on product type and product group, making it easy to find the exact one you need.

Many functions are also included within the Electronic Catalog that allow you to understand product capabilities, compare similar seals, request a quote and much more. The Electronic Catalog is available from the Trelleborg Sealing Solutions website and in the App Store and GooglePlay for mobile use.

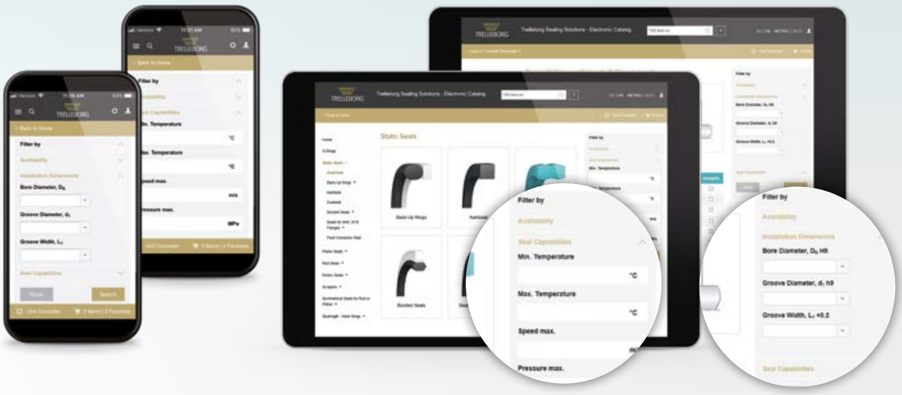


CART/RFQ

The built-in cart function allows you to add products as you search through the catalog. When you are finished, you can review the items in your cart and then submit a Request for Quote. This notifies your local Customer Solution Center and they will be in touch shortly.

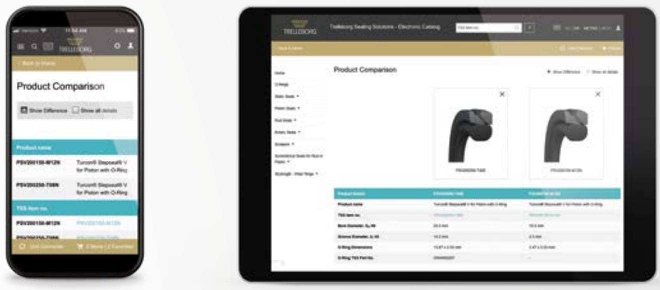
FILTERING

If you have specific operating conditions that the seal must meet and/or installation dimensions, the Electronic Catalog offers a filtering function within the product groups. Here you can input your temperatures, pressure, speed and various installation dimensions to filter products that can meet your needs.



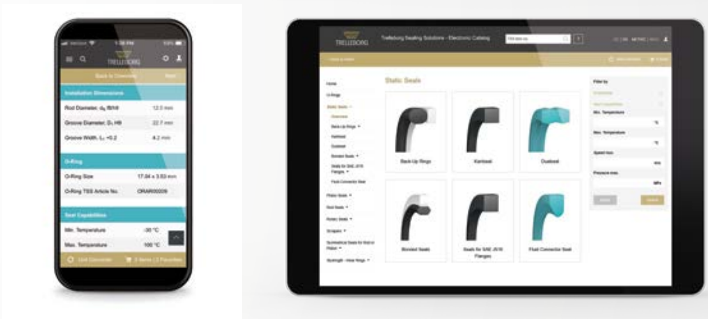
PRODUCT COMPARISON

When looking through the catalog, you can choose to compare multiple products. The product comparison function allows you to select which products you are interested in, and then puts all relevant information into a table for your review. You can even choose to display all product details side by side or to only show the fields where they differ.



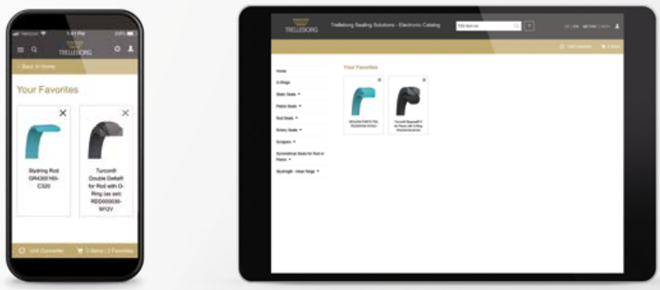
PRODUCT INFORMATION

Detailed product information is available for each part number. Once you select a specific part number, you will be able to see its installation dimensions, seal capabilities, related catalogs and other information. From this page, registered users can access the material data sheets that are applicable to the part number.



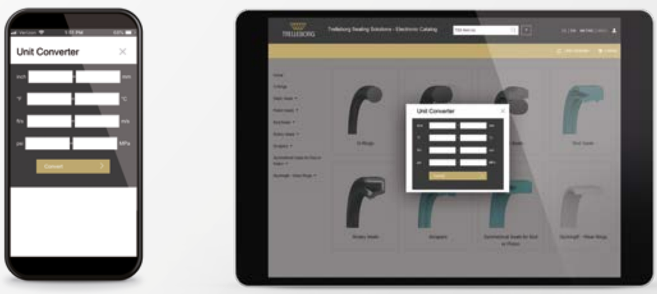
ADD TO FAVORITES

Do you have a part that you frequently look up or need information on? You can now save any of our part numbers as a favorite that is linked to your account. Anytime you log in to the Electronic Catalog, your favorites will be a click away!



UNIT CONVERTER

If you are looking at a product and need to know the conversion between metric and imperial, you can use the Unit Converter tool that is available at the top of the screen for web users and at the bottom for mobile.



HiMod® Advanced Composite Bearings (HiMod® ACB)

General Description

HiMod® Advanced Composite Bearings (HiMod® ACB) are a high-performance solution for bearing, wear ring, bushing, and thrust washer applications manufactured using Automated Fiber Placement (AFP) technology.

The in-situ additive manufacturing process uses high-quality, pre-impregnated tape for a robust and low friction bearing solution. Two types are available depending on friction requirements: ACB Standard, which uses a carbon fiber/PEEK tape, and ACB+ with an additional low friction PEEK layer. Both versions use selected solid additives to enhance and tailor their performance.

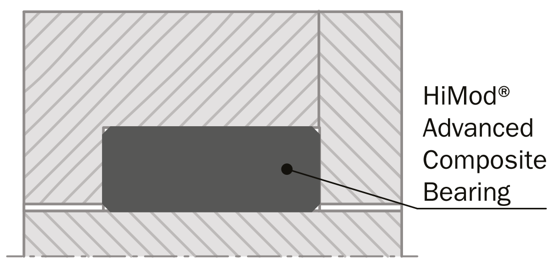


Figure 1: HiMod® Advanced Composite Bearing

AUTOMATED FIBER PLACEMENT (AFP)

Automated Fiber Placement (AFP) is a proprietary, patented technology to form structures in situ by melting and consolidating unidirectional pre-impregnated material with high heat and pressure.

The reinforcing fibers within the structure can be oriented at any angle between zero (axial) and 90 degrees (hoop) to customize the stiffness, deflection, Coefficient of Thermal Expansion, wear, and thermal management of the resulting product. AFP produces consolidated structures with continuous fibers placed in the load paths required. Automated robotic manufacturing makes the process precise and repeatable for reliable serial production.

FEATURES AND BENEFITS

- Lightweight with high specific strength and extremely high bearing load
- Handles abrasive wear with high Pressure Velocity (PV) values for a long service life
- +274 °C / +525 °F continuous service temperature
- Low friction and prevents galling
- Allows tight tolerances of mating components
- Withstands short-term dry-running (ACB+ available for longer periods without lubrication)
- Nearly zero Coefficient of Thermal Expansion (CTE) with traditional layup (higher CTE available)
- Virtually no moisture absorption and high chemical resistance
- Maintenance free

APPLICATION EXAMPLES

Trelleborg Sealing Solutions has supplied both newly designed and replacement/aftermarket composite wear rings and bearings to pump OEMs and end users for nearly three decades.

Pump applications include:

- Upstream Energy / Petrochemical Processing / Oil Refineries
- Nuclear Power Plants
- Flood Control
- Desalinization and Reverse Osmosis

In addition, these products are ideal as bearings for:

- Aerospace Landing Gear
- Industrial High Load Bearing Applications

FOR MORE INFORMATION

Scan the QR code to learn more about Automated Fiber Placement (AFP) technology.

Table 1: Bearing Properties Summary

	ACB Standard	ACB+	Test Method
	Carbon Fiber/PEEK	Carbon Fiber/PEEK Backing with Solid Lubricant-filled PEEK Liner	
Max. Compression Strength MPa (ksi) Through-thickness direction	1.338 (194)	896 (130)	ISO 604
Modulus MPa (msi) Through-thickness direction	10.342 (1.5)	8.687 (1.26)	ISO 604
Max. Operating Temperature °C (°F) Varies with loading and constraints	149 to 274 (289 to 525)		-
Coefficient of friction Dynamic, dry, chrome plate steel	0.15	0.07	In-house friction/ wear test
Max. PV value MPa-m/min (psi-ft/min) Dry, max. tested 4.57 m/s (900 fpm), 31 MPa (4,500 psi), 1018 Steel, 0.4 +/- 0.05 µm (16 ± 2 µin) R_a	525 (250.000)1)	- 2)	1) ASTM D3702 2) In-house PV test Reached test machine limit before failure
Wear Factor 10^{-8} mm³/N-m (10^{-10} in³ min/ft. lb. hr.)	8.823 (4.38)	-	In-house friction/ wear test
Type of Maintenance	Maintenance Free		-
Coeff. Linear Thermal Expansion 10^{-6}/°C (10^{-6}/°F) Varies with layup	0.27 to 30.6 (0.15 to 17.0)	0.27 to 30.6 (0.15 to 17.0)	-

HiMod® ACB raw material is unidirectional continuous carbon fiber reinforced PEEK, 60% fiber volume. Test conditions are at +23 °C / +73 °F, ambient. Friction and wear properties vary with test method, countersurface material, roughness, ambient conditions, and PV combination.

TYPES

Two primary types are available to cover most applications:

ACB Standard
Continuous carbon fiber / PEEK structural layer. Typical dynamic coefficient of friction values range from 0.15 to 0.3, dry-running.

ACB+
Continuous carbon fiber / PEEK structural layer with low friction PEEK liner and internal solid lubricant (liner available on ID, OD, or both). This low-friction option brings a nominal dynamic coefficient of friction value of 0.07, dry-running.

Further customizations include, but are not limited to:

- Up to 5x higher coefficient of thermal expansion (CTE) in the circumferential direction.
- Higher strength/stiffness carbon fiber (IM7/PEEK). Cost and availability may vary.

Contact your local Customer Solution Center for further customization, including different polymer or fiber options.

QUALITY

HiMod® ACB are high-performance composite structures made to strict quality standards. Certification of the production facility is in accordance with Aerospace Standard AS9100, meeting the specific requirements for quality control and management. Quality control is managed from the initial purchase of raw materials, throughout manufacturing to the inspection of the final fabricated product. Each manufactured structure maintains traceability down to the raw material level. Components are inspected throughout manufacturing with regularly calibrated equipment.

R&D TESTING FACILITIES

Trelleborg's worldwide test facilities offer tribological, mechanical, thermal, and customized testing regimes. The rotating tests employed within this manual for wear and friction characterization are simulated based on actual applications and tested with either dry or lubricated samples. Mechanical tests include compressive, tensile, flexural, shear, and hardness, at either the material or component level to closely match application conditions. Several tribological tests are also available for PV values, wear rate, and wear factor.

CERTIFICATIONS

Continuous carbon fiber / PEEK composite meets API 610 standard as a qualified material for stationary or rotating components.

SIZES AND AVAILABILITY

Components are usually supplied as fully machined products to a customer drawing, with assistance from Trelleborg Sealing Solutions engineers to design for manufacturing and installation of composites.

Alternatively, semi-finished stock cylinders are available on request.

Readily available sizes for machining include:

- Outer diameter of 50.8 mm to 342.9 mm in 12.7 mm increments (2 to 13.500 inches in 0.500 inch increments)
- Wall thickness of 19.05 mm (0.750 inch) nominal
- Lengths of 152.4 mm (6 inch) or 1,219.2 mm (48 inches)

Custom diameters and lengths are available on request, ranging from an inner diameter of 6.35 mm to an outer diameter of 1,524 mm (0.250 inches to 60 inches), and up to 9 m (30 feet) lengths; wall thickness capability of over 356 mm (14 inches) is greater than the requirements of most applications.

Table 2: Cylinder Dimension Limits

	Min.	Max.
Diameter	6.35 mm (0.250 inches)	1,500 mm (60 inches)
Length	6.35 mm (0.250 inches)	9 m (30 feet)
Thickness	0.13 mm (0.005 inches)	Over 300 mm (1 foot)*

*Contact your local Customer Solution Center for thicknesses of 300 mm (1 ft) or over.

Flat sheets are also available on request up to 1,200 mm by 600 mm with 75 mm thickness or greater if needed (4 ft by 2 ft with 3 inch thickness).

Properties/Specifications

RAW MATERIAL DATA SHEET

Table 3: Typical Material Properties – Continuous Carbon Fiber / PEEK Composite

Color	Black
Density	1.603 g/cm³ (0.058 lb/in³)
Fiber Weight Percentage	68%
Fiber Volume Percentage	61%
Glass Transition Temperature (T_g)	+143 °C / +289 °F
Crystallization Temperature (T_c)	+289 °C / +552 °F
Melting Temperature (T_m)	+345 °C / +653 °F
Water Absorption (+100 °C / +212 °F, 15 days)	+0.23% Weight Change
Shore D Hardness (Unidirectional Laminate)	95
Coefficient of Friction	0.10 to 0.33

Table 4: Mechanical Properties

Temp.	0° Tensile Strength	0° Tensile Modulus	0° Comp. Strength	0° Comp. Modulus	90° Tensile Strength	90° Tensile Modulus
-55 °C / -67 °F	2,068 MPa / 300 ksi	137.9 GPa / 20.0 msi	–	–	98.6 MPa / 14.3 ksi	10.5 GPa / 1.52 msi
+23 °C / +73 °F	2,069 MPa / 300 ksi	137.9 GPa / 20.0 msi	1,358 MPa / 197 ksi	124.1 GPa / 18.0 msi	86.2 MPa / 12.5 ksi	10.2 GPa / 1.48 msi
+82 °C / +180 °F	2,034 MPa / 295 ksi	137.9 GPa / 20.0 msi	1,255 MPa / 182 ksi	124.1 GPa / 18.0 msi	82.7 MPa / 12.0 ksi	9.6 GPa / 1.39 msi
+121 °C / +250 °F	2,000 MPa / 290 ksi	137.9 GPa / 20.0 msi	1,172 MPa / 170 ksi	124.1 GPa / 18.0 msi	–	–
IL Shear Strength (Unidirectional Sample, +23 °C / +73 °F, In-situ process)						62.1 MPa / 9.0 ksi
In-Plane Shear Strength (+/- 45° Sample, +23 °C / +73 °F)						171.7 MPa / 24.9 ksi

Table 5: Coefficient of Thermal Expansion (CTE, α)

Temperature (°C / °F)	Longitudinal (0°)	Transverse (90°)
-55 °C / -67 °F	0.01 x 10^{-6} m/m/°C 0.006 x 10^{-6} in/in/°F	27.0 x 10^{-6} m/m/°C 15.0 x 10^{-6} in/in/°F
+23 °C / +73 °F	0.27 x 10^{-6} m/m/°C 0.15 x 10^{-6} in/in/°F	30.6 x 10^{-6} m/m/°C 17.0 x 10^{-6} in/in/°F
+121 °C / +250 °F	0.50 x 10^{-6} m/m/°C 0.28 x 10^{-6} in/in/°F	43.2 x 10^{-6} m/m/°C 24.0 x 10^{-6} in/in/°F
+232 °C / +450 °F	1.01 x 10^{-6} m/m/°C 0.56 x 10^{-6} in/in/°F	75.6 x 10^{-6} m/m/°C 42.0 x 10^{-6} in/in/°F

Revision F, 92023. Raw Material Safety Data Sheets are available upon request.

BEARING STIFFNESS AND STRENGTH

ACB Standard

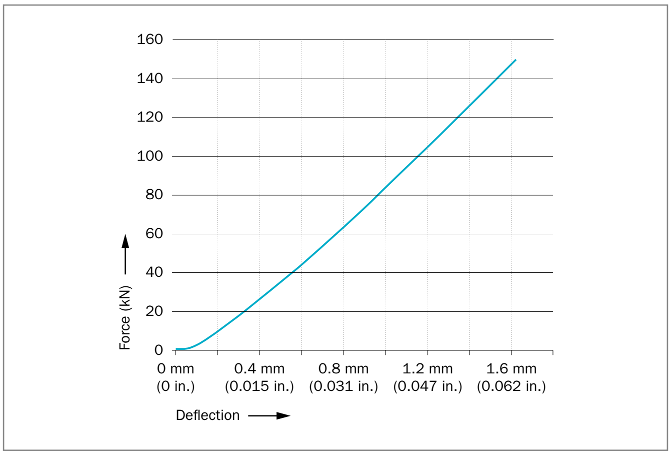


Figure 2: ACB Standard Compression Test Results

Compression Test Conditions

Speed:	1.3 m/min / 4.3 ft/min
Sample size:	11.54 mm / 0.454 inches high by 11.92 mm / 0.469 inches diameter

Results:
Ultimate Strength, through thickness:
1,342 N/mm^2 / 194 ksi

Average modulus, through thickness:
10,342 N/mm^2 / 1.5 msi

ACB Standard:
Rockwell HRM 210

ACB+

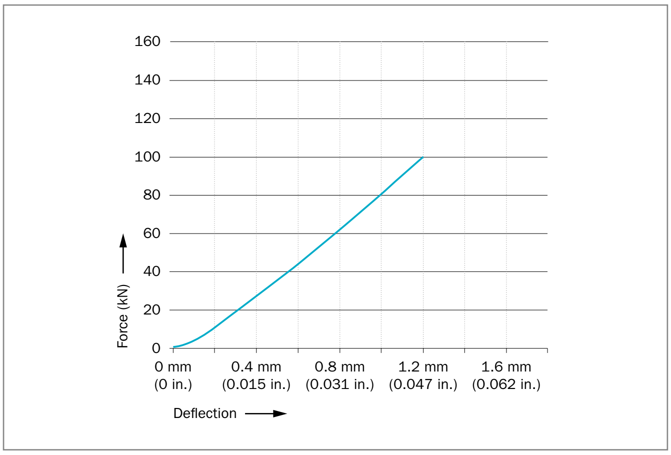


Figure 3: ACB+ Compression Test Results

Compression Test Conditions

Speed:	1.3 m/min / 4.3 ft/min
Sample size:	Round button, 12.2 mm / 0.480 inches high by 11.9 mm / 0.469 inches diameter

Results:
Ultimate Strength*, through thickness:
900 N/mm^2 / 130.5 ksi

Average modulus*, through thickness:
8,716 N/mm^2 / 1.23 msi

ACB+:
Rockwell HRM 110

*Results vary with liner thickness

ELECTRICAL RESISTIVITY/PERMITTIVITY

HiMod® ACB are available primarily as carbon fiber/PEEK or S2 fiberglass/PEEK where higher electrical resistivity or permittivity is required. Contact your local Customer Solution Center for information on custom anti-static compounds or special features.

CHEMICAL RESISTANCE

Comprised of unsized carbon fiber and PEEK, HiMod® ACB holds high solvent compatibility up to +200 °C / +392 °F. Carbon is inert and PEEK has been used in extreme environments in multiple industries since the 1980s. A spectrum of PEEK's chemical compatibility is available from various material suppliers. Contact your local Customer Solution Center for assistance.

MOISTURE ABSORPTION

AS4 Carbon Fiber / PEEK is hydrolytically stable and absorbs 0.2% by weight (water submersed at +100 °C / +212 °F for 15 days). This allows very low dimensional change upon machining or in service. The material has been used as structural components in submersed seawater and harsh fluid environments for applications spanning years and sometimes decades.

ACB STANDARD TRIBOLOGICAL PROPERTIES

ACB Standard is often used in hydrodynamic environments where dry-running is not required. When dry-running is required, ACB+ is recommended.

All tribological results and properties listed are heavily dependent on the tested material and opposing surface, environmental conditions, pressure, and velocity – they are not inherent to material alone. These factors include counterface material, surface roughness, and hardness. Values listed should be used as a design guide only and parts should be tested in service conditions.

Several results are shown at varying test conditions, including dry- and water-lubricated.

Dry-running tests include both cylindrical (Plint) and Pin-on-disc tests. Friction values in Table 6 were obtained with the in-house Plint test diagrammed in Figure 4.

Plint Test

Table 6: ACB Standard Dynamic Friction Values

Pressure N/mm² (ksi)	Dry		Water lubricated	
	Static Friction	Dynamic Friction	Static Friction	Dynamic Friction
5 (0.73)	0.22	0.20	0.12	0.10
10 (1.45)	0.20	0.18	0.14	0.12
15 (2.18)	Material Breakdown	Material Breakdown	0.11	0.08
20 (2.90)	Material Breakdown	Material Breakdown	0.11	0.08

Plint Test Conditions

Plint Test Machine	
Cylindrical Samples	
Diameter Shaft	100 mm / 3.937 in
Shaft Material	316L Stainless Steel
Contact Dimensions	40 x 50 mm / 1.574 in x 1.968 in
Contact Pressure	5, 10, 15, 20 N/mm² / 0.73, 1.45, 2.18, 2.90 ksi
Shaft Speed	1m/min / 3.28 ft/m
Shaft Surface Roughness	0.6 mm / 0.023 in R_a
Test Lubrication	Dry and water

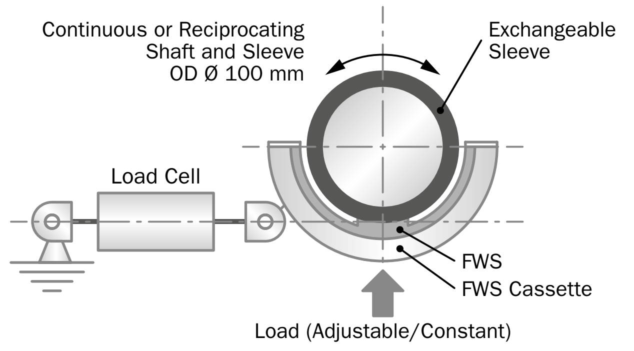


Figure 4: Plint wear test stand diagram

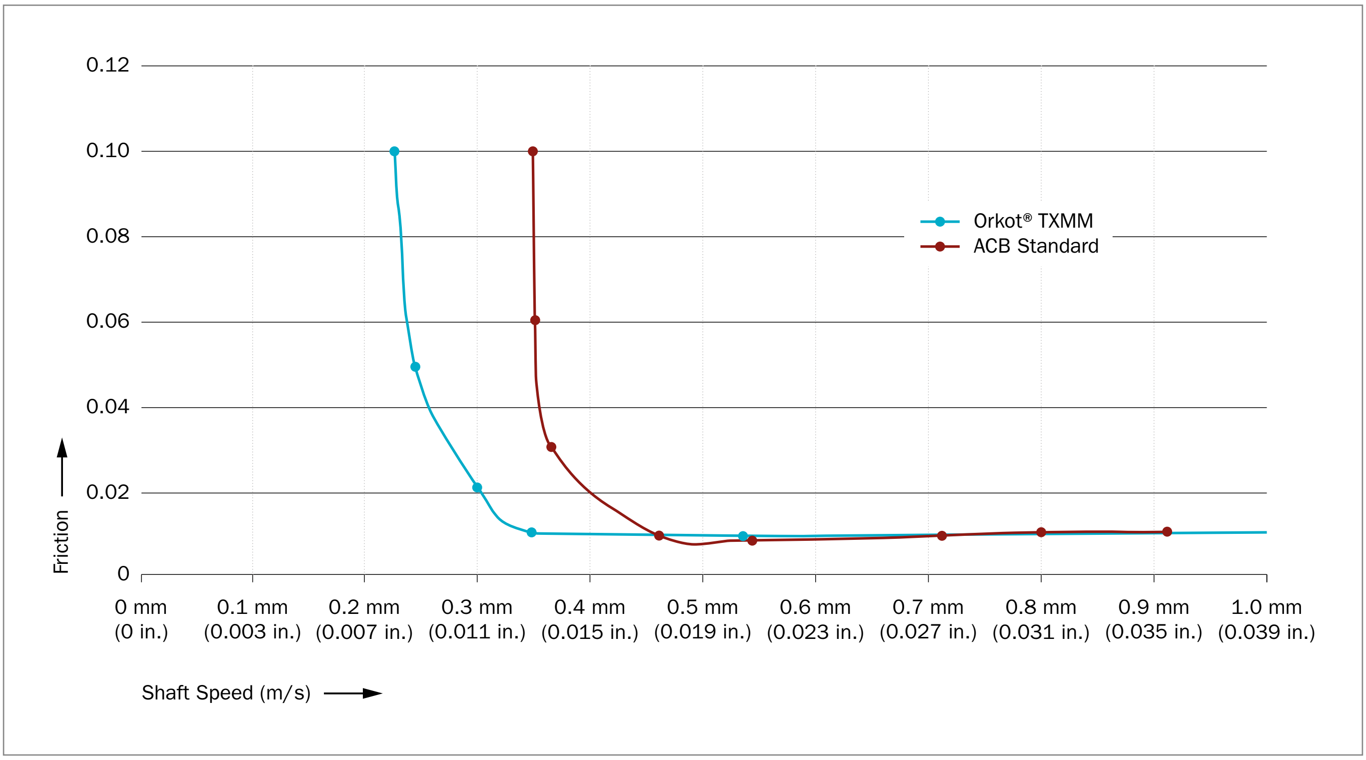


Figure 5: Striebeck Curves for ACB Standard compared with Orkot® TXMM, 316 Stainless Steel Shaft (0.5 N/mm² / 72.52 psi)

For reference, Orkot® TXMM is shown. The curve was also obtained using the Plint test setup.

Pin-on Disc Test

Table 7 indicates relatively high PV conditions which showed no signs of test sample degradation evident after test. Trelleborg can test at specific conditions upon request.

Pin-on Disc Test Conditions

ASTM	D3702
Dry running	
8 hour duration	
Counterface	1018 Steel, R_a = 0.4 +/- 0.05 μm / 16 +/- 2 μin
Velocity	16.9 m/min / 55.5 ft/min
Pressure	31 MPa / 4,500 psi

Table 7: ACB Standard Friction and Wear Values at given PV

Input	Results			
PV Setpoint MPa - m/s (psi-fpm)	**Dynamic Friction Coeff.,** RMS	**Wear Rate** m/s (in/min)	**Wear Factor,** K $mm^3/(N\text{-}m)10^{-8}$ $(in^3\text{-}min/(ft\text{-}lb\text{-}hr)10^{-10})$	**Surface Temperature,** RMS °C (°F)
350 (250,000)	0.162	4.78E-09 (1.13E-05)	63 (31.4)	220.94 (429.7)

Linear Oscillating Wear Test

Table 8: ACB Standard Water Lubricated Tribological Properties

	Number of Tests	Wear Factor, K	Coefficient of Friction		Break-in Wear
		$mm^3/(N\text{-}m)10^{-8}$ ($in^3\text{-}min/(ft\text{-}lb\text{-}hr)10^{-10}$)	Dynamic	Break-out (Static)	m (inches)
ACB Standard (CF/PEEK)	6	8.8 (4.38)	0.067	0.306	1.1201E-05 (0.000441)
316L Stainless Steel	2	49,768.1 (24,685.00)	0.372	0.455	N/A**
Aluminum Bronze	2	7,259.1 (3,600.50)	0.235	N/A*	N/A**
Nickel Copper Alloy	4	58.0 (28.76)	0.233	0.699	9.8679E-05 (0.003885)
Chromium-based Alloy	4	144.4 (71.62)	0.188	0.697	0.0001824 (0.007181)
PEEK w/ filler	4	69.8 (34.63)	0.067	0.275	4.031E-05 (0.001587)

Linear Oscillating Wear Test Conditions

In-house linear wear test machine	
Tap water lubricated	
Diameter buttons	10 mm / 0.393 inches
Linear reciprocating stoke (sinusoidal velocity profile)	5 mm / 0.196 inches
Counterface	HVOF coated WC plates (R_a = 0.05 to 0.1 µm / 2 to 4 µin) ground perpendicular to the sliding direction
Pressure	6.894 MPa / 1,000 psi

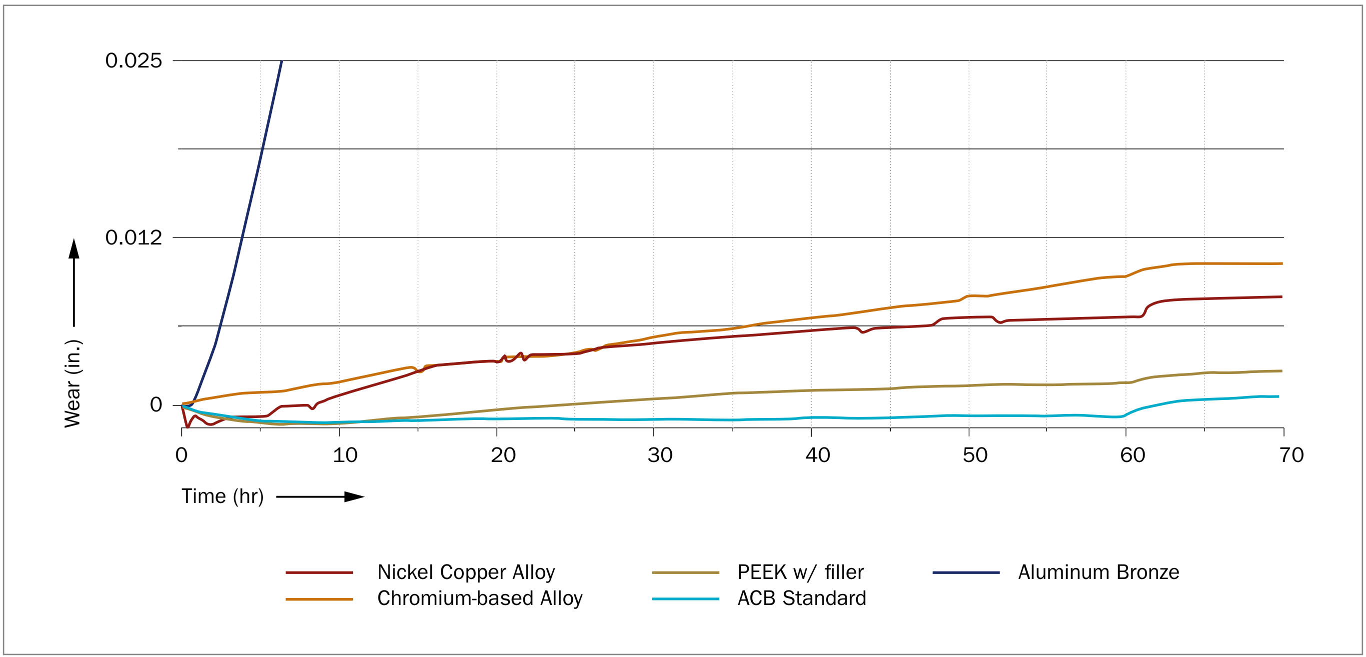


Figure 6: Wear of ACB Standard in water lubricated, room temperature environment compared with other materials

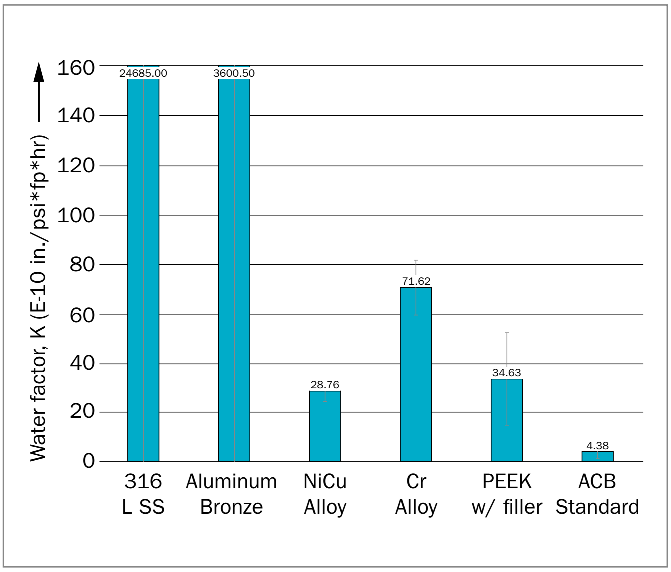


Figure 7: ACB Standard – Wear Factor in water lubricated room, temperature environment with 90% confidence intervals

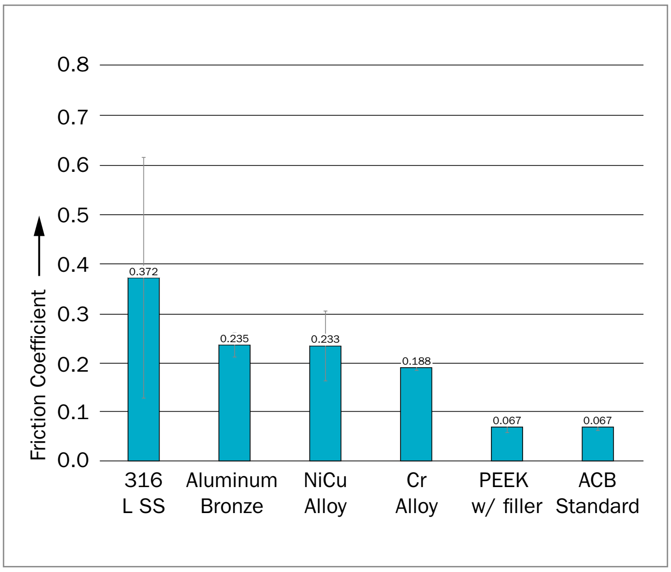


Figure 9: ACB Standard – Dynamic Friction in water lubricated, room temperature environment with 90% confidence intervals

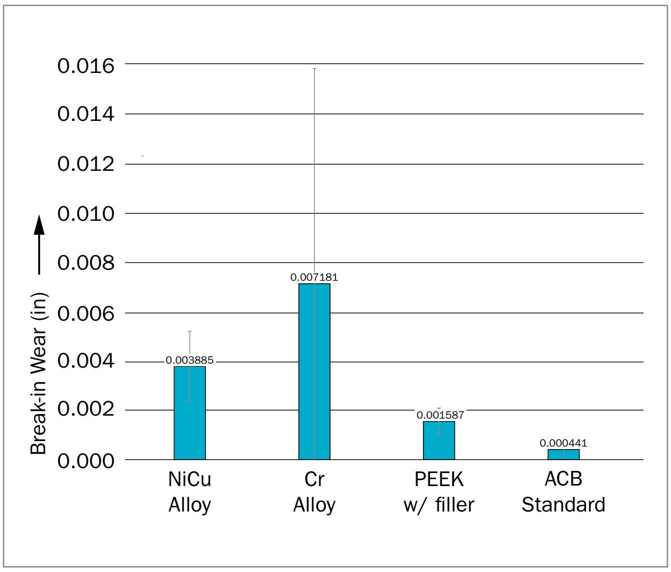


Figure 8: ACB Standard – Wear in water lubricated, room temperature environment with 90% confidence intervals

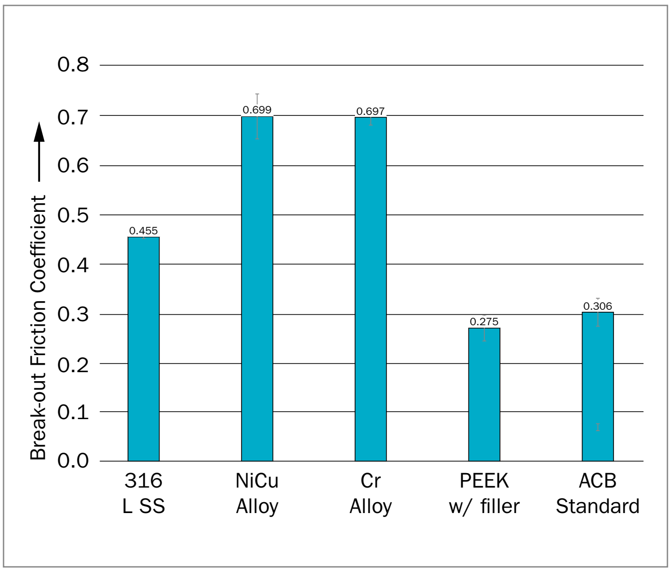


Figure 10: ACB Standard – Static Friction in water lubricated, room temperature environment with 90% confidence intervals

ACB+ TRIBOLOGICAL PROPERTIES

ACB+ (Carbon Fiber/PEEK with solid lubricant and low-friction PEEK liner) is used where dry-running is required.

Plint test

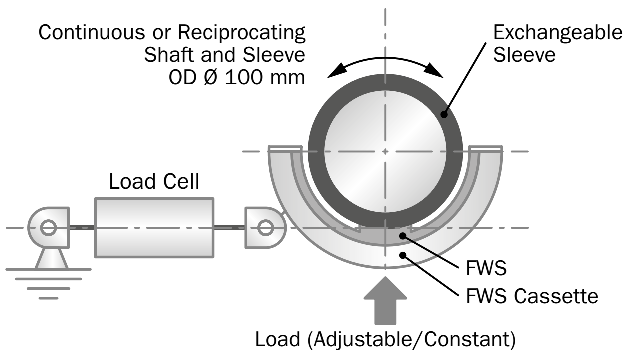


Figure 11: Plint wear test stand diagram

PV values were generated with the same in-house Plint test machine as used for the ACB+ Friction Values test (see Figure 12). Dynamic friction during testing never exceeded 0.08 at all contact pressures.

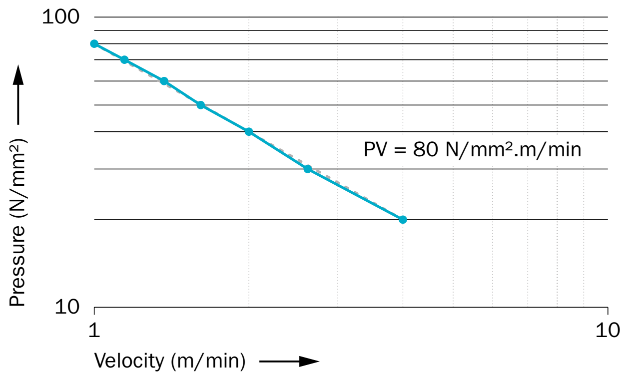


Figure 12: PV Values – ACB+

Table 9: ACB+ Friction Values

Carbon/PEEK+ with liner, Dry Conditions		
Pressure N/mm² (ksi)	Static Friction	Dynamic Friction
5 (0.73)	0.16	0.13
10 (1.45)	0.05	0.04
20 (2.90)	0.07	0.05
40 (5.80)	0.07	0.06
60 (8.7)	0.07	0.06
80 (11.6)	0.08	0.06
100 (14.50)	0.08	0.07

Test Conditions for ACB+ Friction Values

Bearing Material	ACB+
Cylindrical samples	
Shaft Material	316 Stainless Steel
Surface Roughness	0.6 µm
Lubrication Dry	
Shaft Motion Reciprocation	±15° (30° Arc)
Bearing Pressure	5, 10, 20, 40, 60, 80 and 100 N/mm²
Average Shaft Speed	0.6 m/min
Test Cycle Duration	24 hours

Test Conditions for PV Values

Bearing Material	ACB+
Shaft Material	316L Stainless Steel
Lubrication Dry	
Shaft Motion Continuous	Single direction
Bearing Pressure	Variable (20 – 100 N/mm²)
Shaft Speed	Variable (1 – 4 m/min)
Contact Area	20 x 50mm (2000 mm²)
Counter-Face Finish	0.6 µm R_a

Design Information

INSTALLATION

HiMod® ACB should be mounted with an interference fit where possible, with the entire bearing length fully supported to minimize stress concentrations and shear loads.

The general installation procedure is as follows:

1. Oversize composite OD by a nominal amount for 3XX or 4XX series stainless steel housing shown in Table 10 and Table 11 respectively.

2. Machine composite ID undersized by 0.5 to 0.8 mm (0.020 to 0.030 inches) to be finished after fit.

3. Press fit via hydraulic press with leading edge chamfer on composite and housing. The entire area of the composite should be pressed upon to ensure no interlaminar shear loads while pressing. Light oil may be used as a lubricant.

Thermal fits may also be used where needed. In a thermal fit, most diametrical change will come from the steel, as the standard composite design Coefficient of Thermal Expansion is nearly zero in the circumferential direction. Heating metal above +260 °C / +500 °F is not recommended for composite contact, or per metallurgy limits of metal.

Split rings and mechanical fasteners for anti-rotation may also be used. Contact your local Customer Solution Center for design assistance per application.

WALL THICKNESS

An ID to thickness ration of 10:1 is generally suitable for a composite cylinder, varying per application. The wall thickness range for wear rings is usually 3.18 to 25.4 mm (0.125 to 1 inch). Thicker or thinner walls are available and may be recommended depending on length or loads on the cylinder.

Contact your local Customer Solution Center for recommendations on wall thickness per application. This is driven by system pressure and diameter/thickness ratio.

DESIGN TOLERANCES

Tight machining tolerances are achievable as needed, with as low as +/- 0.013 mm (+/- 0.0005 inches) possible. Typical bushings and bearings are recommended as follows:

Bearing OD mm (inch)	Typical Manufacturing Tolerance mm (inch)
12.7 – 254 (0.5 – 10)	0.05 (0.002)
254 – 1,524 (10 – 60)	0.10 (0.004)
> 1,524 (60)	*

* Contact your local Customer Solution Center

Bushings with a length to diameter ratio greater than one may require a larger tolerance.

SURFACE ROUGHNESS FOR BOTH ACB AND ACB+

The following surface roughness is achievable:

- 0.2 µm / 8 µin may be achieved on any surface if ground.
- 0.8 µm / 32 µin is standard ID (tool surface).
- 1.6 to 3.25 µm / 64 to 128 µin is standard OD surface.

Table 10: Nominal Interference fit at metal/composite diameter for 3XX Stainless Steel Bore, CTE 17.1 x 10^{-6} / °C (9.5 x 10^{-6} / °F)

Bore Diameter mm (Inch)	Operating Temperature, °C (°F)					
	-73 (-100)	24 (75)	93 (200)	149 (300)	204 (400)	260 (500)
51 (2)	51 (0.001)	0.03 (0.002)	0.05 (0.004)	0.11 (0.006)	0.16 (0.008)	0.21 (0.01)
76 (3)	76 (0.002)	0.04 (0.002)	0.05 (0.006)	0.14 (0.008)	0.21 (0.011)	0.28 (0.014)
102 (4)	102 (0.002)	0.05 (0.002)	0.05 (0.007)	0.17 (0.01)	0.27 (0.014)	0.36 (0.018)
127 (5)	127 (0.003)	0.06 (0.003)	0.06 (0.008)	0.2 (0.013)	0.32 (0.017)	0.44 (0.022)
152 (6)	152 (0.003)	0.08 (0.003)	0.08 (0.009)	0.23 (0.015)	0.37 (0.02)	0.52 (0.026)
178 (7)	178 (0.004)	0.09 (0.004)	0.09 (0.01)	0.26 (0.017)	0.43 (0.023)	0.59 (0.03)
203 (8)	203 (0.004)	0.1 (0.004)	0.1 (0.011)	0.29 (0.019)	0.48 (0.026)	0.67 (0.034)
229 (9)	229 (0.005)	0.11 (0.005)	0.11 (0.013)	0.32 (0.021)	0.54 (0.03)	0.75 (0.038)
254 (10)	254 (0.005)	0.13 (0.005)	0.13 (0.014)	0.35 (0.023)	0.59 (0.033)	0.83 (0.042)
279 (11)	279 (0.006)	0.14 (0.006)	0.14 (0.015)	0.38 (0.025)	0.64 (0.036)	0.91 (0.046)
305 (12)	305 (0.006)	0.15 (0.006)	0.15 (0.016)	0.41 (0.027)	0.7 (0.039)	0.98 (0.05)

Table 11: Nominal Interference fit at metal/composite diameter for 4XX Stainless Steel Bore, CTE 10.8 x 10^{-6} / °C (6.0 x 10^{-6} / °F)

Bore Diameter mm (Inch)	Operating Temperature, °C (°F)					
	-73 (-100)	24 (75)	93 (200)	149 (300)	204 (400)	260 (500)
51 (2)	51 (0.001)	0.03 (0.002)	0.05 (0.003)	0.09 (0.005)	0.12 (0.006)	0.15 (0.007)
76 (3)	76 (0.002)	0.04 (0.002)	0.05 (0.004)	0.11 (0.006)	0.15 (0.008)	0.2 (0.009)
102 (4)	102 (0.002)	0.05 (0.002)	0.05 (0.005)	0.13 (0.007)	0.19 (0.01)	0.25 (0.012)
127 (5)	127 (0.003)	0.06 (0.003)	0.06 (0.006)	0.15 (0.009)	0.22 (0.012)	0.29 (0.014)
152 (6)	152 (0.003)	0.08 (0.003)	0.08 (0.006)	0.16 (0.001)	0.25 (0.013)	0.34 (0.017)
178 (7)	178 (0.004)	0.09 (0.004)	0.09 (0.007)	0.8 (0.011)	0.29 (0.015)	0.39 (0.019)
203 (8)	203 (0.004)	0.1 (0.004)	0.1 (0.008)	0.2 (0.013)	0.32 (0.017)	0.44 (0.022)
229 (9)	229 (0.005)	0.11 (0.005)	0.11 (0.009)	0.22 (0.014)	0.35 (0.019)	0.49 (0.024)
254 (10)	254 (0.005)	0.13 (0.005)	0.13 (0.009)	0.24 (0.015)	0.39 (0.021)	0.54 (0.027)
279 (11)	279 (0.006)	0.14 (0.006)	0.14 (0.01)	0.26 (0.017)	0.42 (0.023)	0.59 (0.029)
305 (12)	305 (0.006)	0.15 (0.006)	0.15 (0.011)	0.28 0.018	0.46 (0.025)	0.63 (0.032)

LAMINATE FIBER ARCHITECTURE (LAYUP)

A laminate subject to one-directional wear is generally manufactured with fibers in the same direction as the wear to utilize the self-lubricating nature of carbon fiber. However, a low-friction PEEK liner and custom Coefficient of Thermal Expansion (CTE) is available upon request. Transverse to fibers, the CTE is ~100 times greater than it is in the fiber direction. Figure 13 shows options for the average CTE of a laminate by varying the average angle. Note that the CTE of the laminate is bidirectional in the hoop and axial axes. This is only an approximation as CTE varies non-linearly with temperature.

A laminate's modulus is direction-specific and can vary from stiff (matching fiber modulus) to compliant (matching transverse fiber modulus). A design should account for the specific application and may require attention to CTE, modulus/deflection, and directional wear goals. Contact your local Customer Solution Center for custom design assistance.

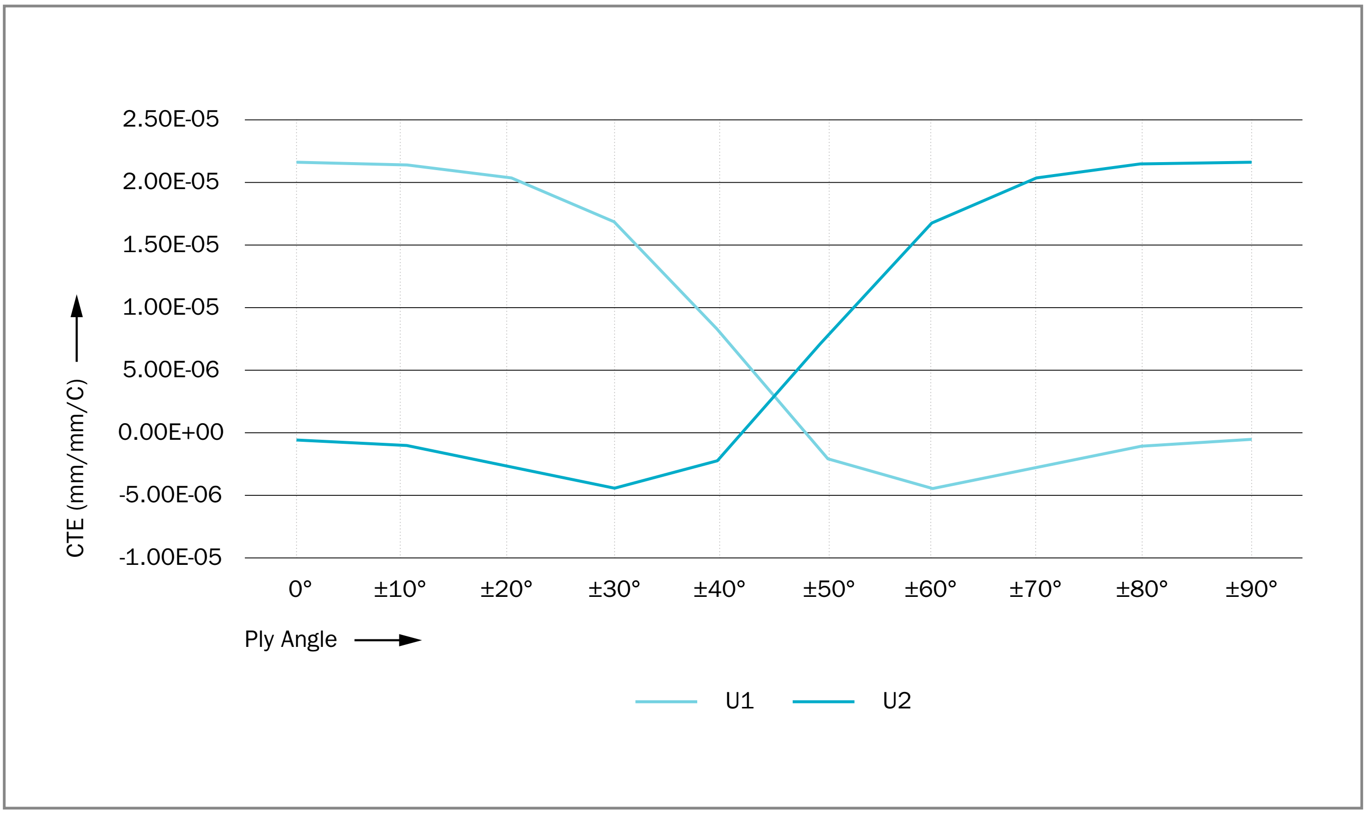


Figure 13: Coefficient of Thermal Expansion versus average angle in a cylindrical structure

COUNTERFACE

The wear surface counterface should have a surface roughness between R_a = 0.4 to 0.8 µm (8 to 32 µ inch).

For interference fits, a metallic housing requires a reasonably machined tolerance on its bore, typically according to BS EN 20286-2:1993 H7.

There should be no sharp edges on any grease paths or other discontinuities.

ACB+ is self-lubricating, but if grease is required, circumferential grooves may be machined in the bearing to assist grease distribution.

For applications in hydrodynamic wear, helical or axial grooves may be machined into the composite to assist fluid boundary layer distribution.

As with all laminated composites, best results are most often obtained with the bearing surface parallel to or concentric with the ply layers. For example, loads on the end of a flanged bushing may require a separate thrust washer. Care must be taken with the design components subject to compression, bending, or shear loads along the direction of lamination.

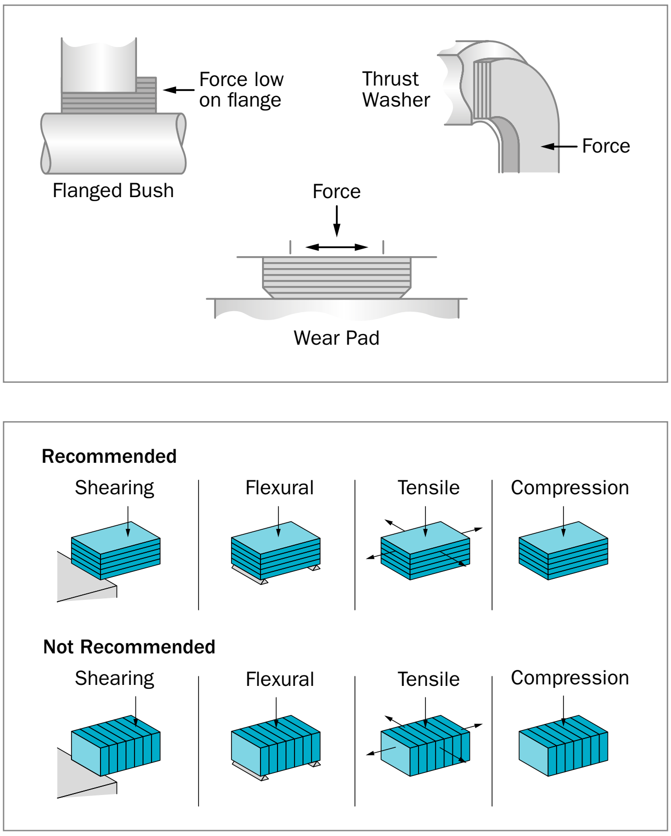


Figure 14: Loading diagram recommendations

MACHINING HIMOD® ACB

This guide addresses the fundamental approach for machining, drilling, and turning continuous fiber reinforced composite structures. Like machining metals, trials are recommended for all cases, however, specific considerations detailed below aim to reduce trial time. These guidelines help to avoid stressing the material in unfavorable states that lead to fracture. Varying a material's fiber, resin, or fiber/resin interface will influence results.

Cutting Tool Material
Polycrystalline Diamond (PCD) tooling provides the highest hardness and often best wear resistance in machining composites, compared with carbide, high speed steel, and diamond coated tools. Still, a relatively short tool life is still expected compared with metal machining. This applies to tool tips for parting, turning, and coated tools for milling routers, end mills, and saws. PCD has higher upfront costs than carbide and other options, but overall project costs tend to be lower due to improved tool life.

Tolerances and Stability
Dimensions on Carbon Fiber Reinforced Polymer (CFRP) structures can typically be controlled to less than 0.03 mm (0.001 inch) if necessary. Residual stress in laminates may manifest as a change in part shape but this is accounted for in part design. Dimensional instability is especially rare in closed section structures such as cylinders.

Thermal Management
The heat caused by friction between tool and part should be managed to prevent resin from melting and distorting. Use of coolant, slower feeds, and smaller cut depths all help prevent such temperature elevation. Coolant of 50/50 mix of isopropyl alcohol and water is often used since it will not contaminate the structure and because it will partially evaporate and cool the part. The thermal properties of the polymer within the composite must be understood during machining: engineering thermoplastics such as PEEK have a melt temperature near +343 °C (+649 °F), whereas commodity thermoplastics, such as HDPE, melt at up to several hundred degrees less with a melt temperature near +135 °C (+275 °F).

Surface Roughness

Most CFRP structures can be ground, honed, or polished to a surface roughness (R_a) of less than 0.127 µm / 5 µin if needed. Surface quality derives from the quality of tape including fiber wet-out, and the quality of the laminating process. With thermoplastic composites, the grinding can melt the plastic at the structure's surface. Lathe operations and milling can typically achieve roughness between 0.812 and 1.625 µm / 32 µin and 64 µin R_a.

Delaminations and Fiber Pull-out

Fiber breakout and interlaminar de-bonds are the primary concern when machining CFRPs. The general goal is to compress the laminate during machining whenever possible. When milling, clamping free edges near cuts helps mitigate stress risers and prevent fiber blowout and de-bonds. Similarly, reinforcing far side thru-holes during drilling with a temporary plug helps avoid fiber breakouts and delaminations. Some laminates may not need clamping during cuts, but this should be tested in trials.

Milling operations benefit from herringbone/counter-helix style flutes that force the laminate into compression during cutting.

Abrasive waterjets are effective for cutting composite laminates. Cutting accuracy depends on thickness and speed and are typically 0.076 mm (0.003 inches) and 0.13 mm (0.005 inches). The kerf (cut width) typically ranges between 0.5 mm (0.020 inches) and 1.0 mm (0.040 inches). More sophisticated waterjets can correct for kerf variation from cutting speed, "jetlag", and taper error for tolerances approaching 0.03 mm (0.001 inches). Waterjets with 2 axes are common for flat panels and six axes can be used for complex parts.

Ultrasonic machining may be used on CFRPs but is usually most effective on harder materials such as ceramics or ceramic matrix composites. Micro sized oscillations reduce cutting force and tool wear of conventional cutting tools. However, ultrasonic equipment is less universally present and versatile than standard machining equipment.

Health and Safety

All dust from fiberglass, carbon, or other CFRPs should be contained through coolant, dust extraction devices, and typical personal protective equipment to avoid skin, eye, and respiratory irritation.

Carbon-based composites can yield electrically conductive dust, which should be contained, especially around electronic equipment.

Additional Information

- Machining trials typically yield the optimal combination of cutting force, speeds, tool wear, and surface roughness.
- Fixtures used in composites machining are chosen per application, as with metals. Acetal plastic is often used for its stability, softness, and ease of machining.
- The fibrous nature of the material yields less consistent chips than a monolithic granular structure of metal. Plies with fibers in the direction of cutting yield strands, as opposed to plies cut perpendicular to cut, which yield shorter chips.
- Some fiber breakout at machined surfaces is common. This is usually only an issue to avoid short dust-sized splinters while handling. Sometimes a grinding finishing process is sought for better finish. Fiberglass components may tend to fray more than carbon based, and a final grinding or polishing step may be needed.

APPLICATION CHECKLIST

To ensure correct design, consider all of the following details and consult your local Customer Solution Center for assistance:

- ☐ What problems are to be solved using HiMod® ACB?

- ☐ Housing considerations:
  - ☐ What will the installation method be?
  - ☐ What will the counterface material, roughness and hardness need to be?
  - ☐ What sealing surface requirements are there?
  - ☐ How long is the duty cycle?

- ☐ Chemical and mechanical properties:
  - ☐ What bearing load is required?
  - ☐ What will the surface speed be?
  - ☐ What will the operating temperature range be?
  - ☐ What fluids will the product encounter? (chemical exposure, abrasive media)
  - ☐ What do the Coefficient of Thermal Expansion requirements in hoop and axial directions need to be?
  - ☐ Are there any deflection (or stiffness) requirements in hoop and axial directions?
  - ☐ Do you require electrical insulation?
  - ☐ Does the design limit interlaminar shear loading?

- ☐ Type of movement:
  - ☐ Is the movement one-directional rotating, or oscillating?
  - ☐ Will there be any shaft misalignment?
  - ☐ Does the application require anti-rotation features?

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Version no. 99OO166GBGAO124