Appendix D – Machining Guidelines

A. Holding and Chucking

When holding any composite billet or part it is important to remember that, unlike metallic materials, polymers will deform/distort under excessive holding pressures. This is very important when machining parts/billets with a thin cross-section (0.250 in / 6.35 mm or under) and for finish machining. Parts/billets that are held too tightly may spring back after release from the holding mechanism and result in parts that are not concentric and/or undesirable dimensions.

1. Standard Jaw Chucking

Four or six jaw chucks are acceptable for thick cross-section parts and billets. Ensure medium chucking jaw pressure to prevent material distortion.

2. Pie Jaw Chucking

Pie jaw chucking, contacting as close to 90% of the OD as possible, is a superior holding method over standard jaw chucking. This works well for any operation and is preferred over standard chucking for finish machine operations.

3. Adhesive Bonding / Gluing

As an alternate to standard chucking directly to the composite, a billet can be glued to a fixture of alternate material prior to machining operations. If this method is used, it is recommended that guidelines from the adhesive manufacturer be followed to ensure sufficient quantity and coverage. Both Loctite® 4090 and 3M™ Scotch-Weld™ Acrylic Adhesive 8405NS have been successfully used.

4. Holding Fixtures

Use holding fixtures to grip composite components during finish machining operations. Holding fixtures shall contact 100%of either the OD or ID and should be a snug fit (in/out by hand). PTFE is the best material of construction for fixtures with PVC being a close (slightly more rigid) second choice. Fixtures shall allow sufficient holding force without distorting the composite part being machined while being moderately flexible to accommodate the acceptable tolerances from one part to another when making multiple parts from the same drawing. For holding fixtures designed to hold a part by the OD, a metal hose clamp/strap may be used with a flexible PTFE or PVC fixture to guarantee a good hold (compression) if needed. To avoid slippage/loosening while machining, make sure the hose clamp is in good condition.

5. ID Plug Inserts

ID plug inserts are recommended when machining thin cross-section (0.250 in / 6.35 mm or under) parts. The insert can be any material (PVC, metal, etc.) and should be a snug fit (in/out by hand).

B. Coolants / Lubricants

Machining operations (i.e., turning, milling, drilling, or sawing) for these composite materials are typically performed dry without heat build-up issues. However, if heat buildup is excessive, use either mineral oil or a water-based coolant designed specifically for use with polymers. Water-based coolants that contain amine-rust inhibitors may attack some thermoplastic materials and should be avoided. Machining operation specific guidance for coolants and lubricants can be found in the subsequent operation sections of this guide.

C. Turning / Boring / Parting

Properly rough machined composite parts may be finished to exacting tolerances using the recommended tooling along with the feed and speed settings outlined. All sharp, inside corners shall have radii or undercuts to remove possible stress risers. A minimum of 1/32” radius is recommended. All outside corners shall be broken or chamfered to prevent chipping during installation. Generally, maximizing the number final machining passes will provide the most accurate and consistent dimensions with the finest surface finish.

1. Tooling

Use tooling with a .015 to .032” (0.38 to 0.81 mm) radius tip with no chip breaker. Sharp tooling is critical for turning/boring these composites as most issues encountered during machining operations are the result of dull tooling. Standard carbide tooling is sufficient for AR®1, AR®HT and WR®300.

WR®525 and WR®650 materials have a high carbon fiber content and will dull carbide tips and softer tooling rather quickly, resulting in poor surface finish and material "pullout" that appears as pitting. Greene, Tweed recommends PCD diamond (polycrystalline) inserts for single-point machining to achieve accurate and precise results. Consider using two different diamond tools for machining—one for rough cutting and one exclusively for the final dimension passes. This increases accuracy and prolongs the repeatability of completed part dimensions when using the tool designated exclusively for finishing.

When utilizing carbide tooling, be sure to have several sharp tools ready. Exercise caution to avoid ruining parts with dull tooling (especially during finishing operations). Regardless of tooling type, never use dull tooling. Tool bits with PCD (polycrystalline) tips can be specially ground to use as form tools.

It is recommended not to attempt machining final dimensions in one operation. The best practice is to rough machine all dimensions to within .020 in. to .030 in. (.50 mm to .75 mm) of the exact size first, using a set of roughing tools. Then machine parts to the finish dimensions with a set of finishing tools. This process will render good parts with very little to no deformation in circularity and concentricity. Parts shall be held in a holding fixture, or pie jaws, to prevent scarring and marking from clamps or chuck jaws if any additional machining operations are required. Remember to leave 0.02" / .5 mm minimum on the dynamic diameter for final machining after installation. Part off the bearing/wear ring to the minimum axial length of the hardware.

2. Pressed-in Parts

All composite wear parts that are installed via interference fit on the stationary surface should be rough machined to approximately .030" / .75 mm oversized on inner and outer diameters (smaller ID and larger OD) as well as length. First, rough all dimensions. Next, remove the billet from the chuck/jaws. Check that the OD is machining finished to the desired final dimension and parted off. When parted off, the part will appear nonconcentric (egg shaped) but will be restored to original shape once it is pressed into the corresponding housing/holder in the pump. The final inner diameter dimensions are machined after installation in the holder or pump housing by chucking and indicating the complete assembly.

3. Free-state / Floating Parts

Several steps are required to ensure circularity and concentricity of finished parts that are applied as floating components (without interference fit).

- All dimensions shall be roughed to within .040 / .050” (1.0 / 1.25 mm) of the final dimension and the piece parted off.
- Standard practice is to pressure drive the composite part between two plates. Normally, the plate on the backside should be a piece of material held in the chuck and faced off straight. The plate on the front side is a rigid material with a smaller center hold held against the composite part with a live center. The composite part shall be held between these two plates with no chucking pressure on either the outer diameter or inner diameter. The composite part shall be indicated on the outer diameter so as to run concentric enough to clean up at the final dimension size. With minimal pressure on the plates, turn the outer diameter of the piece to final dimensions size using several light finish passes. This should produce a finished outer diameter with minimal deviation of circularity.
- Once the outer diameter is finished to size, hold the outer surface with pie jaws or a snug fit bored fixture to finish inner surface dimensions and lengths.

4. Feeds & Speeds

Back rake angle	0 – 5°
Side rake angle	0°
Side relief angle	5°
End relief angle	15 – 20°
End cutting edge angle	2 – 5°
Side cutting edge angle	0°
Nose radius	1/64” (.40 mm) minimum to 1/32” (0.80 mm) maximum

a. AR®1 / AR®HT

Operation	Cross feed in/rev (mm/rev)	Depth of Cut in (mm)	Surface Speed fpm (mpm)
Rough (Turning / Boring / Facing)	0.006 – 0.008 (0.15 – 0.20)	.090 (2.30)	200 – 400 (60 – 120)
Finish (Turning / Boring / Facing)	0.003 – 0.004 (0.08 – 0.10)	0.005 – 0.010 (0.13 – 0.25)	
Parting	0.002 – 0.003 (0.05 – 0.08)		

b. WR®300 / WR®525 / WR®650

Operation	Cross feed in/rev (mm/rev)	Depth of Cut in (mm)	Surface Speed fpm (mpm)
Rough (Turning / Boring / Facing)	0.004 – 0.006 (0.10 – 0.15)	0.050 – 0.150 (1.3 – 3.8)	700 – 1000 (215 – 300)
Finish (Turning / Boring / Facing)	0.003 – 0.004 (0.08 – 0.10)	0.010 – 0.030 (0.25 – 0.76)	
Parting	0.002 – 0.003 (0.05 – 0.08)		

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D. Milling

Exercise caution when clamping / holding the material to minimize part distortion. AR®1, AR®HT, WR®300 and WR®650 shall be held in a concentric fixture to prevent chuck jaw distortion. AR®1 and AR®HT can be machined following similar guidelines as used when machining aluminum or PTFE materials.

Milling operations used for machining metals can be applied to higher carbon containing composite parts such as WR®525 and WR®650. Coolants designed specifically for use with polymers may be used to help prolong tool life; however, excessive heat buildup is most often the result of dull tooling. A climb milling technique shall be employed to prevent edge chipping of the material.

1. Tooling

Sharp, solid carbide, one or four flute end mills or diamond-tipped end mills are the preferred tooling.

2. Feeds & Speeds

Operation feed:

Rough cut – 8 to 10 inch (200 to 250 mm) / minute

Finish cut – 2 inch (50 mm) / minute

Cutting depth:

Rough cut – up to .25" (6.4 mm)

Finish cut – .005 to .030" (.13 to .75 mm)

E. Drilling

AR®1 and AR®HT can be drilled following similar guidelines as used when machining aluminum or PTFE materials. Drilling procedures for WR®300, WR®525 and WR®650 focus on the prevention of heat buildup, thermal expansion and tool failure. Some preferences are:

- Use a pilot hole when drilling large diameter holes
- Use a peck drilling technique for drilling deep holes to permit intermittent cooling and allow chips to clear the hole
- Back up your work to prevent chip out on the backside of the hole

1. Tooling

Low helix angle design, solid carbide bits are recommended.

2. Tool Geometry

Helix angle – 30°

Point angle – 118°

Lip relief angle – 10 to 15°

Drilling operations are best performed between 500 and 1000 rpm.

F. Sawing

For general cutting, diamond impregnated band saw blades are recommended because of their versatility and reduced heat transfer into the material. Additionally, composite materials will dull carbide tipped and lesser blades quickly. As an alternative, a 6 to 8 TPI carbide tipped saw blade can be used with adequate results. Finer finishes can be obtained using an 8 to 12 TPI blade; however, the more tooth contact, the greater the frictional heat generation.

Precision sawing of composites requires the use of a hollow ground, carbide tipped circular saw blade running at 6,000 to 8,000 fpm (30 – 40 m/s). The tooth set should be 3 – 5° and relief angle and rake angle ground to 15°. The lower the value of the set, the smoother the cut, but tool wear and heat generation will increase.

G. Threading

Composite materials are notch sensitive. Threaded features in plastic materials are not as strong as the same feature in a metallic component. With this in mind, a thread with a rounded root or crest is recommended (sharp V-threads shall always be avoided) for WR®525 and WR®650. It is recommended not to incorporate threaded features in AR®1, WR®300 or AR®HT.

Hand tapping produces an optimum ID thread. For lathe threading, a single-point carbide tool is the best option. Pure mineral oil or tapping fluid should be used, and taps shall never be forced. A lead is strongly recommended to eliminate thread tear. Speeds slower than those used for drilling metals are recommended (40-50% the speed used for drilling metals). Depth of cut on a lathe shall not exceed .005" (0.13mm) per pass and at least two finish passes shall be made once the proper depth has been reached.

H. Grooving

In general, internal and external grooving techniques for these composite materials are similar to those used for metals. Use the same speeds and feeds for grooving these composites as would be used for metals.

In general, groove width will be approximately twice the depth. Depth should never exceed one-third the radial wall thickness. Exact dimensions can be based on available tooling.

1. Straight Grooves

Straight grooves are best machined with a solid carbide end mill (non-carbide tooling will wear/dull quickly). The use of a light coolant or mister will significantly prolong tool life.

2. Spiral Grooves

Form tools are recommended for cutting spiral grooves. Use diamond-tipped inserts or custom ground PCD diamond-form tools for larger quantities. Coolant can be employed, but it does not provide a significant benefit for this type of operation. Spiral grooves are typically created on the lathe in a threading operation but may also be machined on the mill in a thread-mill operation.

3. Radial Grooves

Radial grooves can be created on a lathe or by milling operations.

4. Axial Grooves

External and short internal axial grooves can be created with and end mill. Longer internal grooves are created with a broach operation for AR®1, AR®HT and WR®300 components. Broaching shall not be considered an option for WR®525 or WR®650 due to the high carbon fiber content.

I. Grinding

Grinding composite material is possible but involves special consideration and expense not associated with lathe operations. Moreover, grinding has not proven to yield any benefit over lathe operations in the creation of quality finished components. Grinding is not recommended for these composites. Issues with grinding polymer-based composites include:

- Need for special wheel/stone
- Frequent use of coolant/flush
- Potential for excessive heat buildup
- Buildup of polymer on the wheel/stone

J. Sanding/Polishing

Sanding and/or polishing are not needed or recommended to achieve acceptable surface finishes or the final dimensions required for successful operation. However, if desired, smoother surface finishes may be obtained with the use of emery cloth and polishing pads.

Start sanding with a rough emery cloth (120 grit) transitioning to a finer cloth (320 grit) followed with polishing pads to achieve desired optimum finish. Exercise caution when using a heavier grit/rough sanding cloth and/or excessive sanding. The removal of too much material will result in deviations from tolerance. Sanding and polishing will cause a buildup of heat in the material, which could lead to slight dimensional variations. Final inspection of finished parts should occur in the cooled down state.

Sanding operations should be done at high rpm (500 to 750 rpm) using a fine grit (240 to 320 grit) cloth, followed by Scotch-Brite® or equivalent. It is normal for WR®650 to finish with a rougher surface finish than other composites (~ Ra 125 – 250 μin).

K. Tolerance / Surface Finish Guidelines

Use standard geometric dimensioning and tolerance (GD&T) for all feature tolerances (angularity, concentricity, run out, etc.) except for those features detailed in the following charts. The standard

GD&T is the total tolerance range listed for each diameter in the charts below. This data is driven from the internal standard for composites MS_0009 (table is for reference only).

AR®1, AR®HT, WR®300 and WR®525 will generally have a surface finish between Ra 63µin [1.6µm] and 125µin [3.2µm] with no lapping or polishing necessary. WR®650 will generally have a surface finish between Ra 125µin [3.2µm] and 250µin [6.4µm].

Diameter in. (mm)	**Tolerance AR®1 / AR®HT in. (mm)**	**Tolerance WR®300 in. (mm)**	**Tolerance WR®525 / WR®650 in. (mm)**
< 3 (75)	± .0015 (0.04)	± .0015 (0.04)	± .001 (0.025)
< 6 (150)	± .002 (0.05)	± .0025 (0.06)	± .0015 (0.04)
< 12 (300)	± .0025 (0.06)	± .003 (0.08)	± .002 (0.05)
> 12 (300)	Consult GT Manufacturing		

Appendix D – Installation

Regardless of installation method, it is recommended that users install press-fitted components semi-finished on the dynamic surface. After installation, the dynamic surface should be finished to the designed clearance diameter. Finishing the dynamic surface after installation allows for maximum control of critical size and geometric tolerance. When finish machining is not possible, the dynamic surface diameter can be estimated to change by the same amount as the interference between case/carrier and composite.

Like other ring-shaped plastics, composite components are machined from tube stock and subject to a phenomenon referred to as “egging”. Egging is the term used to describe a circular component that is slightly out of round in a free state. This will occur after parts are machined and removed from the clamping fixture and is usually no more than 0.001/0.0015 inches [0.025/0.038 mm] per inch diameter. Installed components will conform to the mating hardware after installation and when finish machined can be held more concentric to the hardware (generally 0.003 inches [0.076 mm] concentricity).

A. Hydraulic Press

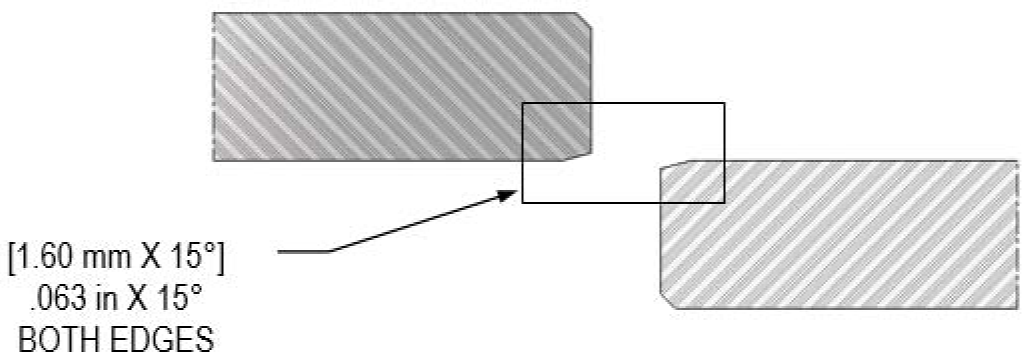
It is standard practice for AR®1, AR®HT, WR®300 and WR®650 that have been designed for interference fit to be installed using a hydraulic press. Ensure lead-in chamfers (and pilot if interference is greater than 1/32” / .80 mm) on both the insert and the housing are present and sharp edges are removed on the metal bore. A plate shall be used to cover the entire top surface of the composite to distribute pressure evenly during installation. Light oil may be used as a lubricant for installation, but is not required.

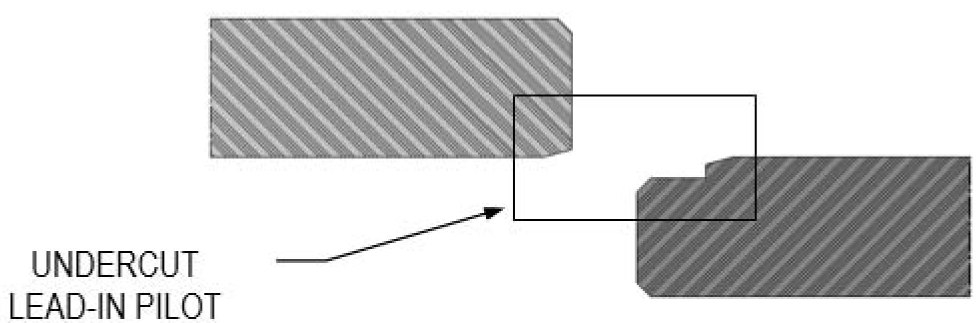
It is acceptable for WR®525 components with less than .008” / .20 mm interference to be installed via hydraulic press. Due to the high stiffness of the material, installation via hydraulic press for WR®525 can be difficult and near impossible for parts longer than 1 inch [25 mm]. In such cases, installation via thermal fitting is recommended. If not possible, parts may be designed for a slip fit (OD .002/.005” / .05/.13 mm undersized to bore) and parts shall be mechanically secured after installation.

For parts made from more than one segment, standard installation via hydraulic press may be difficult. An alternate part design (with reduced interference) or alternate installation method should be considered.

1. Chamfers

When installing via hydraulic press, both the composite and the receiving casing/holder shall be chamfered. For both the holder/casing and the composite insert a 1/16 inches [1.60 mm] long x 15° lead-in chamfer is usually sufficient to guide the insert into the mating hardware. For components that are designed with high interference (above 1/32" / .80 mm) the standard chamfer may not be sufficient. In these cases, the leading edge to be installed shall have a longer chamfer or be undercut prior to the lead-in chamfer. It is important to ensure there are no sharp edges on the metallic component that could possibly damage the composite upon installation.





B. Freeze Fitting (AR®1 / AR®HT)

As an alternative to hydraulic press installation for inserts made from AR®1 or AR®HT, these parts can be freeze-fitted. Liquid nitrogen and dry ice are common cooling agents for freeze fitting. The entire insert shall be completely submerged by the cooling agent until sufficient shrinkage has occurred. Depending on the size of the part, generally one hour is sufficient soak time. Freeze fitting is not recommended for parts made from WR®300, WR®525 or WR®650.

Experienced staff shall be responsible for the handling of either liquid nitrogen or dry ice. Safe handling and ventilation of these cooling agents is beyond the scope of this document.

C. Thermal Fitting (WR®525 / WR®650)

As an alternative to installation via hydraulic press for WR®525 and WR®650 parts, the casing can be heated for installation. When using this method of installation, it is important that the casing be heated to a high enough temperature such that the minimum diameter is at least 0.001 inches [0.025 mm] larger than the maximum composite diameter. To avoid potential heat damage to the composite component the maximum temperature shall be limited to 525°F [274°C] for WR®525 or 500°F [260°C] for WR®650. Direct flame exposure shall be avoided. This method of installation may not be possible with the elevated interference values for components designed for high temperature operation.

If this alternate method is not feasible for installation, WR®525 parts may be designed for a slip fit (OD .002/.005" / .05/.13 mm undersized to bore) and shall be mechanically secured in place. A custom design would be required if attempting this with WR®650.

Due to the increased risk of exposure to temperatures above the recommended upper temperature limit, it is recommended that AR®1, AR®HT and WR®300 not be fitted in this manner.

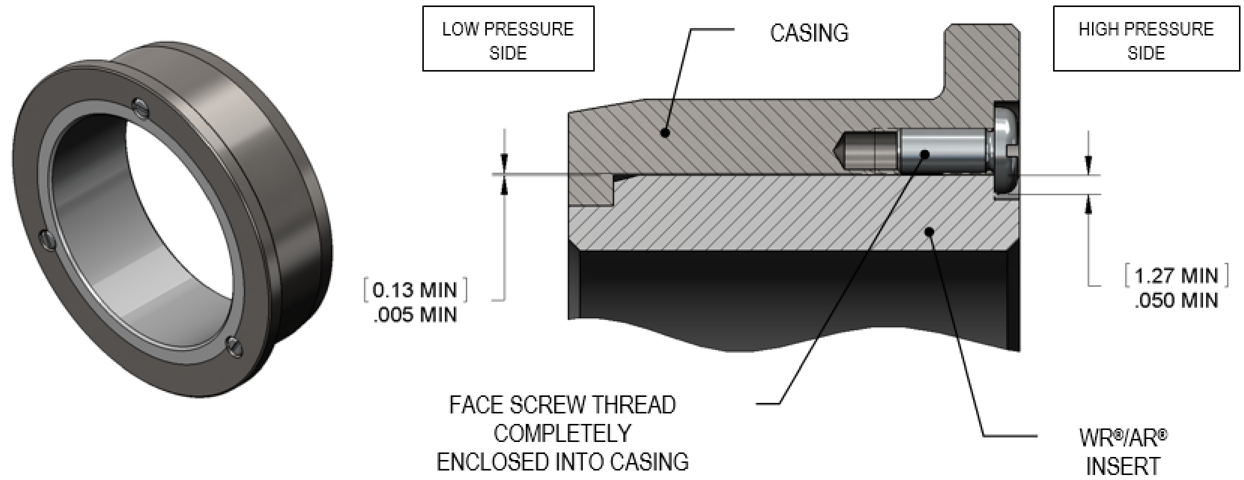
D. Securing Methods

Interface pressure due to interference is generally sufficient to keep press fitted composites from spinning or moving axially under normal operating conditions. For floating components, higher pressure applications or as added security, inserts can be mechanically secured.

OD of insert (inches)	OD of insert (mm)	# Screws/Pins
Up to 5.999	Up to 152.99	3
6.000 – 9.999	153 – 253.99	4
10.000 – 14.999	254 – 380.99	6
15.000 – 19.999	381 – 507.99	8
20.000 – 29.999	508 – 761.99	10
30.000 – 37.999	762 – 965	12

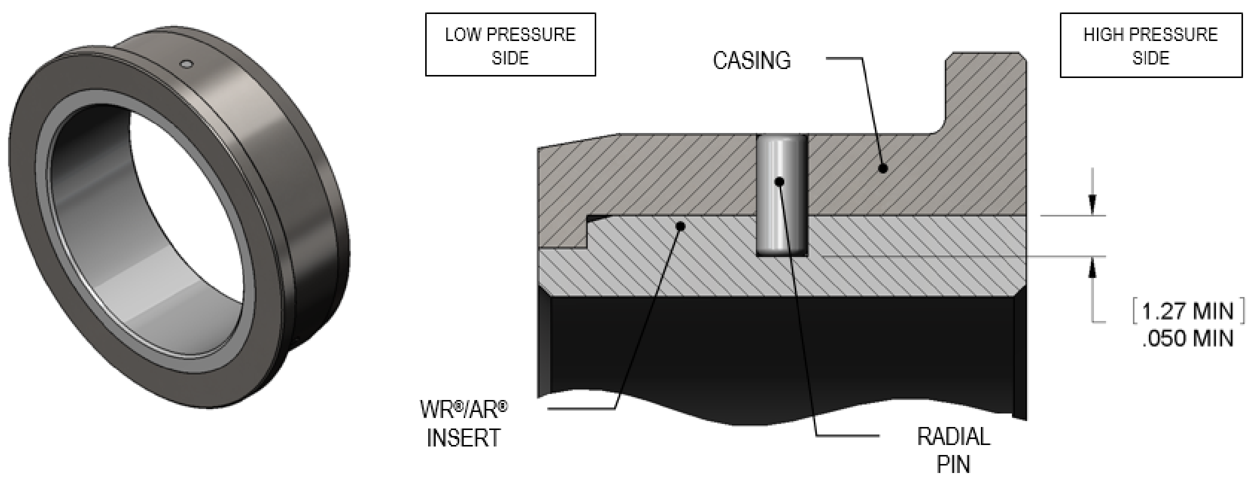
1. Face Screws

When securing composite inserts with face screws, it is important to ensure the screw threads are completely encased by the metallic casing. Leaving 0.005 inches [0.13 mm] radial spacing between the screw thread and the inner diameter of the casing is recommended. The assembly shall be counter bored to ensure no axial protrusion of the screw head after completion. It is also recommended that the securing screw heads have a radial overlap to the insert by a minimum of 0.050 inches [1.27 mm], but not more than 2/3 of the insert radial cross section.



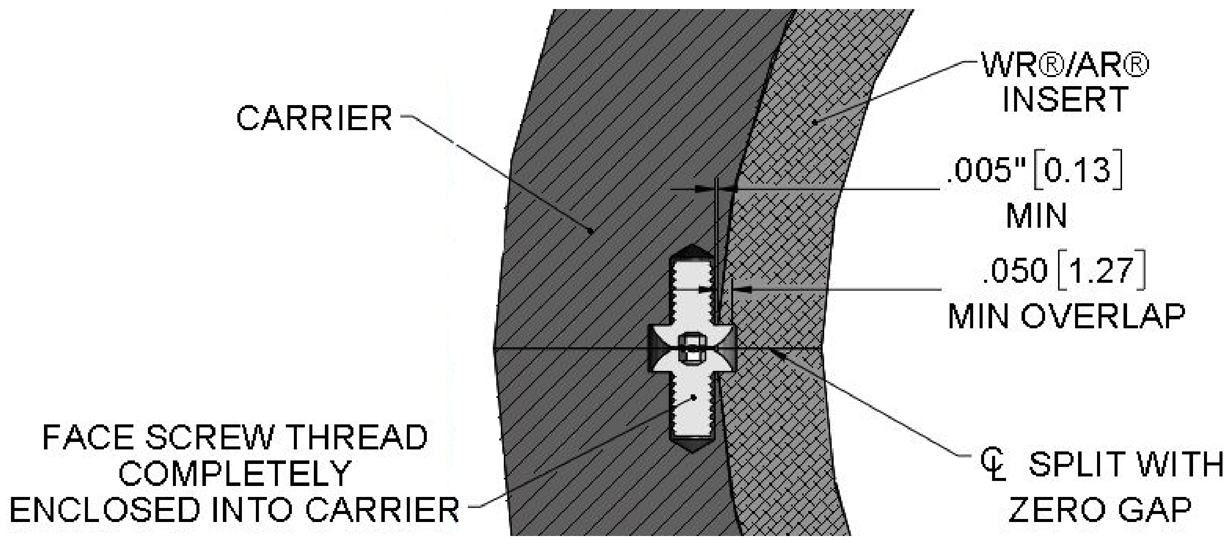
2. Radial Pins

When securing composite inserts with radial pins, it is critical to ensure the pin is deep enough to fix the component in place while not being too close to the dynamic surface of the insert. It is recommended radial pins be inserted to a depth of minimum 0.050 inches [1.27 mm] and a maximum of ½ the radial cross section of the insert. Axial placement should be approximately centered along the entire length of the assembly.



3. Cross Section Screws

When parts are radially split and placed in a carrier, it is preferable to use cross section screws for parts longer than 1.5” [38 mm]. The face screw guidelines apply to cross section screws for spacing and location.



4. Adhesive / Glue

Gluing composite inserts in place is not generally recommended, but is an option when dictated by customer requirement/request. The first consideration is temperature. When service or storage temperature is too high or too low, there may be too large a difference in hardware and composite diameters for the effective retention by adhesive. For this reason, applications should be limited to ambient range +60 to +120°F [+16 to +49°C].

The second consideration is the interaction of the media with the adhesive. The chosen adhesive should be checked to confirm suitability with the media in which it will be operating.

Refer to GTS-6084E section 11.0 for design principles that can be applied for designs that incorporate adhesive retention.