KAMATICSRWG
Engineered Performance

KAron Design Guide



Contents

Kamatics in General

Kamatics Corporation manufactures self-lubricating, maintenance free bearings from common and exotic materials. The liner materials used in the bearings are designated as **KAron** for temperatures to 450°F (232°C), **KAtherm** for temperatures to 500°F (260°C), and **KAcarb** for temperatures to 1200°F (635°C). These three systems encompass a family of self-lubricating bearing liners providing low friction, high load capacity, long life with low rates of wear and a large temperature range. They were developed solely by Kamatics to be used primarily as self-lubricating bearing liners in a variety of applications. This design guide will concentrate on the KAron system.

KAron is a combination of thermosetting resin and filler materials in particle or fiber form. This differs significantly from other self-lubricating materials in that there are no continuous interconnecting fibers or weave that can provide a moisture path to the bonding substrate. A moisture path may either promote corrosion under the liner or significant liner swelling when used in a moisture-laden environment.

KAron liner systems are homogenous in nature, a mixture of resin, polytetrafluoroethylene (PTFE) and other special fillers. Because of this, consistent friction and extremely low, linear, rates of wear can be expected throughout the life of the liner. Other self-lube materials are generally made up of a fabric blanket with different strata of PTFE, fiberglass, nylon, resin etc. and consistent performance cannot be anticipated throughout its thickness.

Characteristics considered in the formulation of KAron include load carrying capability, operating temperature, coefficient of friction, sliding/rubbing velocities or any combination of these.

Another liner option includes KFL-DM. KFL liners are a perfect complement to the KAron liner systems. Kamatics has applied similar technology used in their KAron liner systems and developed the first KFL liner, KFL-DM. KFL-DM utilizes a polymer matrix with special lubricating fillers. It is a film coating which is directly adhered to a metal substrate and supplied in the as-applied condition (no machining). It can be applied to carbon steel, stainless steel, aluminum, titanium, nickel-based alloys, and many other metals and is fully compatible with all aerospace fluids. However, KFL liners are extremely thin (.001”, 0.025 mm) which allows them to be applied in areas that cannot accommodate a full liner thickness.

KFL has performed favorably when tested against several popular DFL coatings, making KFL an ideal choice for static locations that require fretting protection, such as splines and shafting.

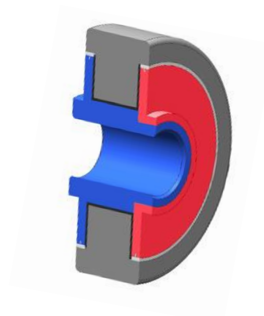

Figure 1
Typical KAron Lined Roller

In addition to typical bearing applications, a KAron liner has other valuable uses including:

- **Salvaging Components** – KAron can be applied in various thicknesses providing a method of salvaging components with oversize bores, undersize OD’s, worn or damaged surfaces, etc. Such applications can be rapidly addressed by a Kamatics representative as to the suitability of Karon as a solution.
- **Fretting Protection** – KAron can be used as an inexpensive barrier to eliminate/prevent damaging contact between expensive components. In many cases, KAron can be used as “applied” without any subsequent machining
- **Corrosion Protection** – KAron has demonstrated limited protection against corrosion while providing a bearing material that can be machined to very close tolerances.

KAron is well accepted throughout the industry. Oil exploration, aircraft, space, marine, nuclear power, hydropower, motorsports, factory automation, heavy equipment are just some of areas successfully using KAron. The operating conditions and parameters vary widely. For example:

- Temperature ranges from cryogenic to over 400° F (205° C).
- Static contact pressures in excess of 100,000 psi (690 mPa).
- Short term operating velocities of 100 feet/minute (30 meters/min) or higher.
- Liner thickness up to 0.060" (1.5 mm).
- Operation with contaminates such as oil, grease, sand, grit, deicer, hydraulic fluid and cleaning fluids, and others.
- Requirement to adhere to various materials including stainless and carbon steels, titanium, copper, nickel and aluminum alloys, fiberglass, carbon fiber and others.
- The need to operate against various materials, hardnesses, and surface finishes.

KAron has definite thickness associated with it. It is not a thin "dry film lubricant" that can be applied after final machining without affecting dimensions. Therefore, space must be provided for the liner when designing components that will include KAron. Liner thicknesses normally range between 0.010 to 0.015 inches (0.25 to 0.38mm). Liner thickness is also a function of the amount of wear or clearance a system can tolerate and continue to operate as intended. For applications where clearance is not an issue, the liner thickness can be increased.

Liner Application

Prior to its application, the surface to be lined should be abraded (roughened) and cleaned to insure optimum adhesion. If the surface to which the liner is to be applied has been shotpeened, the roughening will be kept to a minimum. This is to minimize any adverse effects to the shotpeening. Cleaning of the pre-lined surface is accomplished with chemicals that will not affect the properties of the base material. The liner is applied and cured at temperatures that will not affect the mechanical properties of the substrate.

Applications such as pistons, complex housings, or similar, require design considerations that may not be readily apparent. This is especially true in cases where the customer intends to fabricate the part ***minus the liner*** and then send it to Kamatics for liner application.

Surfaces that are not KAron lined may require protection from the abrading process. This can be a labor-intensive process involving masking. Cost savings can be realized by providing extra material on the non-lined surfaces allowing them to be roughened along with the lined area and later machined to the final dimensions. As KAron is normally machined after application, the extra time to machine the adjacent surface is minimal. **Figure 2** illustrates this technique. The substrate material and KAron liner will be machined in the same setup, resulting in an excellent blending of the two. Kamatics provides the customer with guidance and/or "pre-liner" configuration drawings to coordinate this concept.

Blank **KAron Lined** **Final Machined**

Figure 2

Frequently Kamatics will require the same machining datum the customer used to generate the pre-lined surface. This is for proper tolerance and position of the final KAron lined surface. Any such datum should be identified and agreed upon in advance of any part fabrication.

Design Comments:

- Unless the bearing is molded to size, the KAron liner is normally machined after its application. Therefore, the requirement to hold very close pre-liner dimensions and smooth surface finishes prior to lining is not necessary. Tolerances of ± .002" (0.05 mm) and 125-250 rms (0.8-1.6 um) surface finish on the area to be lined is adequate.
- KAron is unaffected by chromium, cadmium, anodize, and alodine solutions. It is not necessary to protectively mask the liner during these operations. Because of this, the intersection between the plating and liner is virtually gap free. KAron is considered an electrical insulator where plating is concerned. Normal electrical conductivity through the liner to substrate is extremely difficult and cannot be relied upon in normal liner thicknesses.

Journal Bearings

Kamatics Corporation has been designing and manufacturing self-lubricating journal bearings for over 30 years. The original self-lube bearing was manufactured from compact carbon sleeves shrunk-fit into metallic housings. Operating capability of this combination exceeded 1000°F (538°C) and is still in use. They are offered as "KAcarb" bearings. Since then, technological advancements have extended Kamatics products into a larger family of self-lube liner systems called KAron, all exhibiting low friction, low rates of wear, and temperatures ranging from cryogenic to over 1000°F (538°C).

The majority of journal bearings (flanged or non-flanged) are manufactured with a **metallic backing**. The backing can be just about any metal but it is predominately stainless steel and aluminum. However, most composite structures require that the bearing be compatible with the structure. Kamatics Corporation manufactures a large size range of KAron lined bearings with **composite backings.** Carbon/epoxy and fiberglass/epoxy are the most common composite combinations used.

Composite Bearings

Kamatics has "state-of-the-art" computer controlled filament winding and braiding capabilities. Composite backed bearings in excess of 40 inches (1 meter) have been produced. Kamatics KAron lined/composite backed bearings are qualified to MIL-B-85560. Composite bearings for operation at temperatures to 500°F (260°C) are possible with our KAtherm technology.

Kamatics also produces bearings made from **solid KAron**…without any backing for those applications where space is limited. Solid KAron bearings are normally pressed in, or bonded to, a housing and when installed have similar load and performance capabilities of metal or composite backed KAron bearings.

Journal Bearing Design:
A suggested approach to the design of both flanged and non-flanged KAron self-lubricating journal bearings is offered below.

The bearing pressure distribution used in the following equations is in a simplified form. Forgoing extensive discussion on actual pressure distribution and for calculation purposes, assume the area supporting the load to be a "projected area" pressure as defined in **Equation 1.**

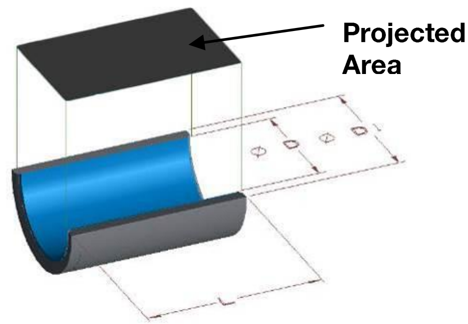

Figure 3, (Non-flanged Journal)

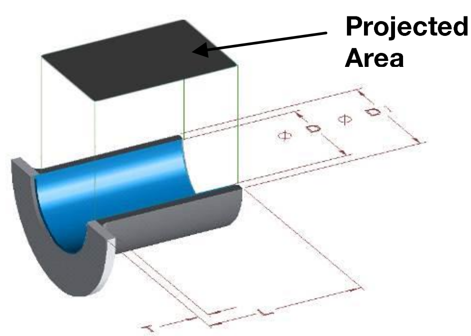

Figure 4, (Flanged Journal)

Equation 1; Journal bearing pressure;
S=P/A, where;

- **S** = Pressure (projected area)
- **P** = Applied load (force)
- **A** = D x L_{EFF}
- D = Nominal journal ID
- L = Nominal length of the journal (including the flange if there is one)
- L_{EFF} = L minus "edge effects"

The "edge effects" are the non-load supporting chamfers and the area under the flange, in the case of flanged journals. The "Projected Area" concept defined is widely used in the bearing industry and most published load ratings are based on this concept.

Sizing of the journal bore is based upon a combination of load, shear and tensile allowables of the bolt/pin material plus any bending under load. The bearing stress on the bearing should be checked once the bolt/pin diameter has been established.

It is important to be as accurate as possible when determining forces and both normal operating and maximum forces are required. For instance, supplying and calculating size based only on the maximum force coupled with an operation or flight spectrum may cause the bearing to be larger than necessary or the amount of calculated wear to be unrealistically high. (Obviously, the bolt/pin has to be selected based on maximum loading among other things.) If the operating time at maximum load is relatively low and cycles are few, it may be overlooked for the initial sizing. This is assuming the loads are within the liner materials capability (below static limit load value). Once initially sized, the amount of wear attributed to the operating extremes can be added to the amount of wear attributed to the normal operating conditions. All movement under load has some contribution to the total wear.

The length of the journal bearing should be kept to a length-to-diameter (L/D) ratio of less than 1.5 to keep both pin bending and edge loading to a minimum. Edge loading can lead to more than anticipated wear. Larger L/D ratios can be designed but only after careful consideration to pin bending is given. Bell-mouths (shallow tapers) machined into the bore will minimize edge loading due to large L/D ratios.

Things to consider in the design of a KAron lined self-lube journal bearing:

- KAron liner material is machineable using conventional turning, reaming or honing procedures. Appendix A explains these techniques. Bearings can be supplied with thicker liner material to allow final machining of the ID after installation.
- Consideration should be given to the type of installation fit between the bearing OD and housing. A press fit will reduce the operating clearance between the bore and mating shaft, and if not addressed, may create an interference with the shaft. **Tables 2** & **3** offer housing dimensions for use with Karon journal bearings.
- As in the case of many journal bearing applications, the bearing manufacturer supplies only one half of the bearing system. The end user supplies the other half (the inner race) in the form of a bolt, sleeve, pin, or similar.
- As noted, the user supplies the mating part and the installation of this part must be carefully controlled. The shaft must be accurately aligned to minimize liner damage during insertion into the bearing. It should have a smooth chamfer or radius on the end that enters the bearing. Fortunately, Kamatics self-lube liners have a significant advantage over fabric self-lube liners in that in the event of localized damage during shaft installation, the damage remains local. There are no interconnecting fibers or weave that will allow the damage to progress and propagate under load until loss of liner or jamming of the shaft has occurred in the bore.
- It is important to select the most corrosion resistant and hardest material with the smoothest surface finish possible for the application under consideration. Consider the use of hard chrome plate to further enhance the shaft finish.
- The selection of mating materials can be a difficult decision and in order not to "over-design", the amount of wear and the type and number of expected operating cycles should be known.
- **Table 4** lists the potential trade-off relative to life with various mating shaft hardnesses and surface finishes. Table 4 displays general "trend" type of information and should not be taken as an absolute value. Kamatics engineering is available for guidance if necessary.

Spherical Bearings

Kamatics Corporation has designed and manufactured self-lubricated spherical bearings since 1966. The original Kamatics spherical bearing was made from compacted carbon matrix liners operating against a chrome oxide coated and polished surface. This was known as a "**KAcarb**" bearing and is still in use today for applications operating at temperatures up to 1200°F degrees F (635°C). Today, as mentioned previously, Kamatics manufactures spherical bearings with **KAron** self-lube liners for temperatures to 400°F (204°C) and **KAtherm** for temperatures to 600°F (315°C). Contact your Kamatics representative for further information for KAtherm and KAcarb applications.

Spherical Bearing Design:
The design criterion for a KAron lined spherical bearing is similar to the criteria for a journal bearing. The major difference is that the inner race is supplied within the bearing assembly and its hardness, surface finish and corrosion resistance is normally left up to the bearing manufacturer.

Important Note: Kamatics KAron lined spherical bearings incorporate a unique "cathedral" shaped cavity between the ball OD and outer race ID. This feature "locks" the liner within the bearing overcoming the familiar problem of liner loss suffered with many fabric lined bearings. **Figure 5** shows the "cathedral" feature.

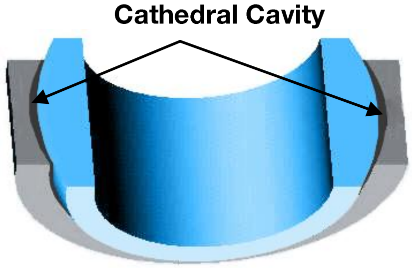

Figure 5

Some other important design considerations relative to the design of spherical bearings follow:

- It is imperative that the spherical surface of the ball be as hard, smooth and corrosion resistant as possible.
- There should be sufficient clamp-up torque applied to the ball faces to insure that motion takes place between the ball OD and outer race liner unless movement within the bore is required.
- For applications where it is difficult to generate enough preload on the ball to prevent rotation between the bore and bolt/shaft, Kamatics can supply the bearing with a KAron liner in the bore and side faces. This will eliminate damage to mating surfaces in the event that motion takes place in the bore.
- Consideration should be given to the type of installation fit between the bearing OD and housing. A press fit will reduce the operating clearance between the ball and outer race and increase the breakout torque if there is initial torque. Either condition may be acceptable for the application. The designer is just cautioned to consider the consequences of the fit.
- Similar consideration should be given to the fit between the ball bore and bolt as noted above. A designer is cautioned not to use an interference fit between the ball and bolt if the ball is hardened 440C stainless steel or other materials that may be prone to stress cracking when under tensile loads.
- Like the previous suggestions for journal bearing installations, for those applications where the user intends to use a thermal fit technique (shrink fit) to install a KAron spherical bearing, a solution of dry ice and solvent in which to immerse the bearing is recommended.

- To assist in housing size selection, **Tables 5 and 6** offer typical housing dimensions for use with Karon lined spherical bearings.

Equation 2 provides a method for calculating bearing pressures for spherical bearings and is similar to the journal bearing "projected area" approach.

Equation 2; Spherical bearing pressure;
S=P/A, where;

- **S** = Pressure (projected area)
- **P** = Applied load (force)
- **A** = $D_{(ball)} \times H_{EFF}$
- $D_{(ball)}$ = Nominal ball OD
- **H** = Nominal width of the outer race
- H_{EFF} = H minus "edge effects"

The "edge effects" are the possible non-load supporting liner setback allowances at each side face of the outer race. In the case of KAron lined spherical bearings, assume the setback at each side to be 0.025 inches (0.63mm) or 0.050 inches (1.27mm) total "edge effect".

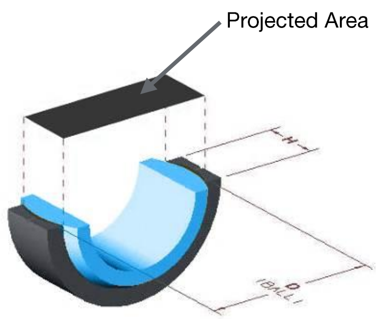

Figure 6,
(Spherical Bearing Projected Area)

Rod End Bearings

Kamatics has over 35 years of experience manufacturing rod end assemblies. Materials range from carbon steel to high nickel alloys. Bore sizes range from 0.060 inch (1.5mm) to 3.00 inches (75mm) and larger. They are used in applications from farm equipment to space shuttles. Kamatics rod ends operate at temperatures ranging from cryogenic to 1000°F (538°F) with KAron, KAtherm, and KAcarb liner systems. "Kamatics KAron Bearing Catalog – Spherical, Rod End, and Journal Sleeve Bearings" (KR-M series) offer some of the more standard sizes of rod ends available. Special sizes are produced upon request. **Figure 7** shows a typical male threaded rod end assembly.

The design of a rod end assembly requires a thorough understanding of the loads it will be subjected to. For example, if the loads are predominately compression (in the direction of the threads or shank), the banjo diameter (the hoop of metal around the bearing insert) can be thinner than if the rod end were used in tension. A tension load on the rod end body causes the hole in the body containing the bearing insert to become elongated (ovalized). Obviously, this elongation does not happen if the load is in compression (in the direction of the shank/threads) as the hole is not "stretched" in this direction.

The elongation creates a "pinching" force on the bearing insert in the 3-9 o'clock position relative to the shank. This can have two significant effects on the assembly. First is that it tends to increase the torque required to rotate the ball. If the magnitude of the torque increase is high enough, coupled with the normal operating torque, frequent oscillation or rotation of the ball may produce unanticipated bending stresses on the rod end body and possibly lead to a fatigue failure at the banjo/shank intersection.

The second effect is relative micro motion between the housing ID and bearing OD at the 3-9 o'clock position as a consequence of the hole elongation. Frequent load reversals between tension and compression can lead to fretting between the bearing and rod end body…and eventual metal fatigue of the rod end. Classic rod end failures occur approximately 15-20 degrees below the 3-9 o'clock position.

A light interference fit between the bearing and rod end body is recommended to minimize the possibility of fretting. Kamatics manufactures spherical bearings to be installed in the rod end body with internal clearance designed to accommodate an interference fit without adding additional ball rotational torque.

The rod end body should be completely analyzed to insure that; the shank/thread size is large enough to support the loads; the banjo diameter is thick enough to react applied forces and minimize hole elongation; the fillet radius between the banjo and shank/threads is of sufficient size and with as good a surface finish as possible to minimize stress concentrations.

Kamatics is available to assist in the design of your rod end application.

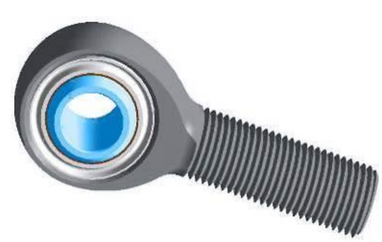

Figure 7 (male rod end assembly)

"KRP" Track Roller, Cam Follower and Pivot Bearings

The design and manufacture of self-lubricating track rollers, cam followers and typical airframe pivot bearings was and continues to be pioneered by Kamatics Corporation. It was obvious that there was an unfulfilled need for this type of bearing that would not be subject to the effects of corrosion, brinnelling, ball/roller/needle fracture and difficulty to grease that is common to conventional anti-friction bearings. The need to continually re-lubricate, the manpower required, not being sure that the lubricant ever reached the bearing, was and continues to be a concern. Also, by eliminating the grease requirement, the environment around the bearing remains much cleaner and not subject to the collection of grit, dirt etc. that is also common around greased assemblies. Looking under the wing or at a landing gear of a greased aircraft is enough to make one aware of the potential benefits of non-greased self-lubricated bearings.

Track Rollers & Cam Followers:
For the majority of track roller/cam follower applications the "**KRP**" design incorporates a KAron liner applied to the OD of the inner race and. Either KAron or PTFE filled Acetal resin is inserted between the side faces of the outer race and thrust members. This provides an additional benefit to the roller by providing a thrust capability not usually found in an anti-friction bearing of the same type. The outer race is made from a hard corrosion resistant stainless steel material, normally Custom 455, 440C or Cronidur 30 stainless steel, and a 17-4 PH stainless steel inner race and thrust member(s). Depending upon the operating conditions, seals are included to minimize the entry of abrasive particles and contaminating fluids. The assembly is then either welded or swaged to keep the components together as an assembly. **Figure 8** illustrates this Kamatics design approach.

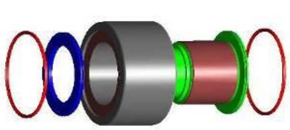

Figure 8 (clevis mounted roller)

The design and load carrying capability of track rollers and cam followers depends heavily on the installation. That is, whether the bearing is installed between a clevis arrangement or is cantilevered off of structure. Of concern for a cantilevered (studded) roller is determining where the roller will contact the mating track or cam. **Figure 9** shows a studded roller assembly.

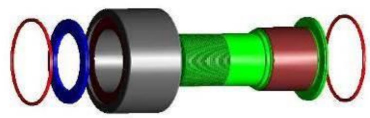

Figure 9, (stud mounted roller)

The worst-case scenario is when the roller contact is at the extreme end of the outer race, away from the threaded end. The bending moment arm is the longest at this point, imparting maximum stress on the stud. This is not a problem unless the stud is not of sufficient size to safely react the implied stress. There are various methods to analyze the bending stresses in a cantilevered roller and this is normally the responsibility of the bearing user. The same concern as to where the outer race will contact the mating surface exists with a clevis-mounted assembly, however, the bending consideration is at a minimum. The concern here is more of track/cam contact and bolt shear stresses. Bolt shear is usually not a major concern as there is double shear involved with a clevis arrangement.

There are ways to minimize the bending concern on a studded roller. One is to incorporate a "crown" radius on the OD of the roller in an attempt to bring the contact point nearer the center of the outer race width. This is the most common approach with anti-friction bearings, however, this ensures that the contact stresses on the track or cam will be high because of the more localized contact area. This is not a problem as long as the stresses are within the material's capabilities.

A second approach to minimizing both the bending and contact stress considerations is the patented Kamatics **self-aligning roller**. This design incorporates a KAron lined spherical inner race that operates against the same hardened outer race material as the more common "KRP" design. The spherical feature allows the roller to conform/align to the mating track/cam surface without the high contact stresses and with a reduced bending moment arm that can be considered to pass through the centerline of the outer race width. **Figure 10** illustrates the self-aligning design.

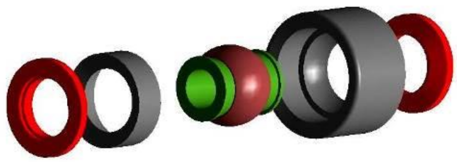

Figure 10, (self-aligning roller)

Extensive testing and field results have shown that a KAron lined track roller will operate successfully for an extended duration at dynamic bearing pressures as high as 20,000 psi (140 mPa). **For most commercial aircraft flap/slat roller applications or similar, by keeping the bearing pressures to a maximum of 12,000 psi (85mPa), the roller can yield in excess of 200,000 revolutions of useful life with liner wear less than 0.004 inches (0.10mm).** This is based on laboratory testing and may vary depending on a number of variables such as speed, temperature, and contamination. As is obvious, if as many as 200,000 revolutions are not required, the bearing pressures can be increased. This is normally the case of military aircraft, where space is small, loads are higher but the number of cycles is lower. Kamatics engineering is available to assist in sizing the roller for any application under consideration.

"KRP" Linkage/Bellcrank Pivot Bearings:
Prior to the Kamatics self-lube KRP design, the typical linkage/bellcrank pivots bearings were mainly limited to ball bearings or greased journal bearings. The "KRP" design for these applications also incorporate a design similar to the track roller/cam follower with an internal self-lube liner, but without the hardened outer race. Because this type of bearing is contained/pressed within a housing the need for a hardened outer race does not normally exist. In "linkage/bellcrank" KRP, the self-lube liner is applied to the ID and side faces of the outer race and the inner race is of sufficient hardness to provide the hard, abrasion-resistant surface necessary for optimum performance. **Figure 11** illustrates this design.

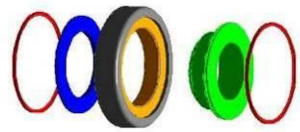

Figure 11
("KRP" Linkage/Bellcrank Bearing)

Table 8 offers some recommended housing and shoulder dimensions for installation.

Kamatics "KRP" catalog offers self-lubricated designs that are dimensionally equivalent to many of the more commonly used ball, needle and roller bearings used in the industry today. They all feature the benefit of a liner system that is not prone to problems associated with anti-friction bearings. Problems such as race brinnelling, rolling element failure, greasing difficulties (including the requirement to get the grease to the bearing) and the manpower needed to maintain the bearing.

For load-carrying capability of a KRP bearing, calculations based on the projected area concept, similar to that previously discussed for Kamatics journal bearings should be used. A KRP linkage/bellcrank bearing normally experiences race oscillation as opposed to race rotation for track roller/cam follower bearings. The data in **Table 7** along with **Equations 3 or 4 and 5** can be used to determine probable liner wear.

Wear Strip Material

Kamatics Corporation offers a unique method of obtaining the KAron liner system in sheet or strip form for special applications. To date, the majority of applications for this material have been in problem areas involving unintentional rubbing, scuffing or fretting. It can also be used when the component to be lined is either too large or too costly to transport to Kamatics for the conventional liner application. **Figure 12** shows some typical wear strip configurations.

The Kamatics KAron wear strip material is in the form of a fiberglass/epoxy backing of variable thickness, with the KAron V liner system applied to one or both sides of the fiberglass. The normal operating temperature range for KAron lined wear material is –65°F (-54°C) to +250°F (+120°C). Operating temperatures up to +500°F (+260°C) are possible with KAtherm T87. Consult Kamatics engineering for further information on the use of high temperature wear material.

Wear strip products are applied by bonding the material onto the substrate with no further machining of the KAron surface anticipated. If necessary, Kamatics can supply complete data for the bonding process along with suggested structural adhesives. Wear strip products consisting of KAron applied onto both surfaces of the fiberglass/epoxy backing are not bonded onto a substrate. These products are generally stamped to size for use as thrust washers.

Light Duty and Medium Duty KAron lined wear strip material is stocked at Kamatics for immediate delivery. Light Duty material, KAron applied to one side, is approximately 0.018 inches (0.46mm) thick with a nominal KAron thickness of 0.008 inches (0.20mm). Medium Duty material, KAron also applied to one side, is approximately 0.036 inches (0.91mm) thick with a nominal KAron thickness of 0.016 inches (0.41mm). Maximum width length dimensions are 12 inches (300mm) x 48 inches (1200mm). Other thickness/size combinations can be manufactured in an expeditious manner to support programs under consideration.

Unless directed otherwise, the typical wear strip material is supplied with a "peel-ply" removable release film on the side opposite the KAron surface. Once removed the surface is ready for bonding. Removal of the peel-ply leaves a clean, roughened textured surface, perfect for the bonding operation. The actual bonding procedures are reserved for the end user, but are generally achieved by use of a two part epoxy adhesive.

Data sheets explaining the properties of **P54 Wear Strip** and **KAron V Wear Strip** material is shown in Appendix D.

Figure 12
Typical Wear Strip Shapes

Bearing Motion

After the bearing pressures have been arrived at, the rubbing velocity of the bearing surfaces and total rubbing distance traveled should be determined. There are several equations to do this and the units are normally expressed in feet per minute (FPM) for velocity and feet for distance.

Equation 3; velocity - oscillation
$V_{(Oscillation)} = ((\alpha * CPM) / (360)) * ((D * \pi) / 12))$, where;

- **V** = Velocity in feet per minute
- α= Number of degrees per cycle
- **CPM** = Cycles per minute
- **D** = Journal ID or ball OD
- **360** = 360° per revolution
- **12** = 12 inches per foot

Calculating the number of degrees per cycle should be calculated using the method shown in **Figure 13**. Figure 13 graphically shows what is understood when the oscillation angle is stated to be ±α° (α indicating any arbitrary angle). It is generally understood that ±α° means "α° times 4", i.e. ±25° = 100° total per cycle. It is not the total included angle times 4. It is extremely important to be accurate on this point otherwise we may have doubled or halved the motion, leading to erroneous wear approximations.

Equation 4; distance - oscillation
$d_{(Oscillation)} = ((\pi * D * \alpha / 360) * N) / 12$,
where;

- **d** = Rubbing distance traveled in feet
- **D** = Journal ID or ball OD
- α = Total degrees per cycle
- **N** = Number of cycles (oscillations)
- **12** = 12 inches per foot
- π = 3.14159…

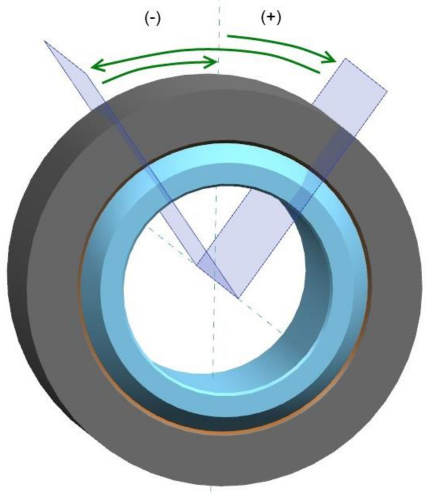

Figure 13,
Oscillation Angle (α) Definition

Equation 5; velocity - rotation
$V_{(Rotation)}$=(D∗π∗RPM)/ 12, where;

- **V** = Velocity in feet per minute
- **RPM** = Revolutions per minute
- **D** = Journal ID or ball OD
- π = 3.14159…
- **12** = 12 inches per foot

Equation 6; distance - rotation
$d_{(Rotation)}$ = ((π∗D∗N)/12
where;

- **d** = Rubbing distance traveled in feet
- **D** = Journal ID or ball OD
- **N** = Number of revolutions
- π = 3.14159 …
- **12** = 12 inches per foot

PV Values, (Pressure x Velocity)
When both bearing pressure (**P**) and velocity (**V**) are determined, the product of the two is a quantity known as "**PV**". This is a value that is used to assist in determining liner wear at various operating conditions.

At Kamatics, many years of endurance test data have been generated for Karon liner materials at various pressures, velocities, and temperatures. **Table 7** displays typical rates of liner wear at various PV levels based on a laboratory environment. The rate of wear is given in inches of wear, per inch of liner travel, at various bearing pressures.

It should be emphasized that when considering PV values, one realizes that a self-lube liner is normally used at velocities less than 20 FPM…and at relatively low bearing pressures at this velocity.

For example, a typical helicopter tail rotor pitch bearing may operate at bearing pressures of 2000 psi (14 mPa) and at a velocity of 20 fpm. This equates to a PV value of 40,000. Similarly, an aircraft slat actuator may operate at a bearing pressure of 20,000 psi (140 mPa) and at a velocity of 2 fpm for a PV value of 40,000. Both are within acceptable PV limits however you would not use the same liner material for both applications. You would use a liner grade that is formulated for either high speed or high load. It would not be advisable to operate at a pressure of 20000 psi and at a velocity of 20 fpm (a PV of 400,000) for any appreciable amount of time.

For most applications, keeping the PV to 50,000 or less will yield relatively long bearing life.

"Life" itself has to be carefully considered as to how long the bearing must operate without exceeding an acceptable amount of wear/clearance. If the application under consideration is required to operate for a relatively short period of time, it is quite conceivable that PV values in excess of 100,000 can be acceptable...again, depending on the duty requirements of the bearing. Any time the requirement is for a PV in excess of 50,000, Kamatics engineering should be contacted for advice.

Wear Calculations

Equation 7 incorporates values obtained from Table 7 to arrive at a predicted amount of liner wear after an assumed operation sequence.

Equation 7; Wear Calculation
W = k ∗ d
where;
W = total liner wear in inches
k = wear rate from **Table 7**, in inches of liner wear per foot of liner travel.
d = total liner distance traveled in feet obtained from Equations 4 or 6.

Example: Assume a typical application is operating at a bearing pressure (P) of 25,000 psi, at an average rubbing velocity (V) of 1.5 feet per minute and for a distance of 5000 feet. The product of the "P" and "V" is well within the allowable range noted earlier. From Table 7, locate the point where the 25,000 psi ordinate intersects the "wear" curve, and follow this intersection point to the left, parallel to the "x" axis and obtain the "**k**" wear factor of 3800 E^{-10} or 3.8 E^{-7}. Multiply this "k" factor times the number of feet traveled and obtain the amount of liner wear of 0.002 inches (0.05mm) of liner wear. To this add 0.0005 inches (0.013mm) of "liner seat-in" that may occur within the first 100 feet of travel, for a potential total liner wear of 0.0025 inches (0.063mm).

Bearing Installation

There has been much written pertaining to bearing installation and many companies have established their own preferences. MIL-STD-1599 offers some excellent basic recommendations relative to fit-up and dissimilar metal considerations. The following is offered to complement MIL-STD-1599 with respect to Kamatics bearings.

Journal Bearing Installation
The self-lube liner on a journal bearing is normally supplied unprotected other than standard wrapping and packaging. Once removed from its packaging, handling and installation damage can be a major concern.
It is important to protect and not subject the liner to external damage during the installation process. The tool used to insert the bearing into the housing must be free of sharp corners with smooth beveled edges where it enters the bearing. The edges of the housing into which the bearing is being assembled should be chamfered to assist in centering the bushing.

In the case of a journal with a lined flange, the insertion tool should have a surface as large as the flange OD to apply the insertion force against. This will protect the liner on the flange as well as the liner within the bore. The force applied to the bearing should be firm, steady and in one continuous effort. Pausing before complete insertion may cause galling of the bearing OD, housing bore or both. **Figures 14 and 15** offer installation suggestions and **Tables 2 and 3,** housing and shaft sizes. **Figure 16** shows various methods used to retain journal bearings.

In applications where the user intends to use a thermal fit technique (shrink-fit) to install a KAron journal bearing, Kamatics recommends a solution of dry ice and an environmentally safe solvent in which to immerse the bearing. If the housing is to be heated to increase the bore size for easier entry of the bearing, the temperature used to heat the housing should not cause the bearing temperature to exceed 325°F (163°C).

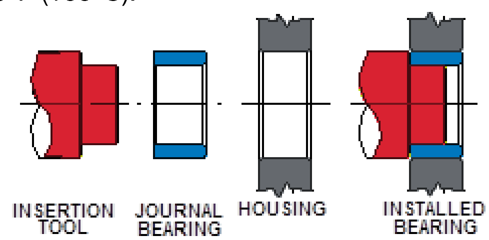

Figure 14
(Non-flanged Journal Bearing)

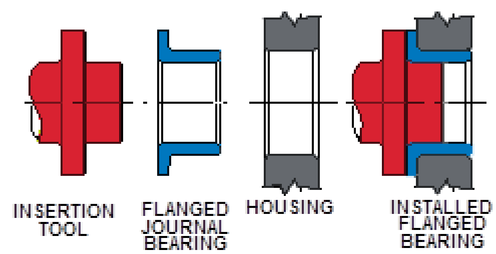

Figure 15
(Flanged Journal Bearing)

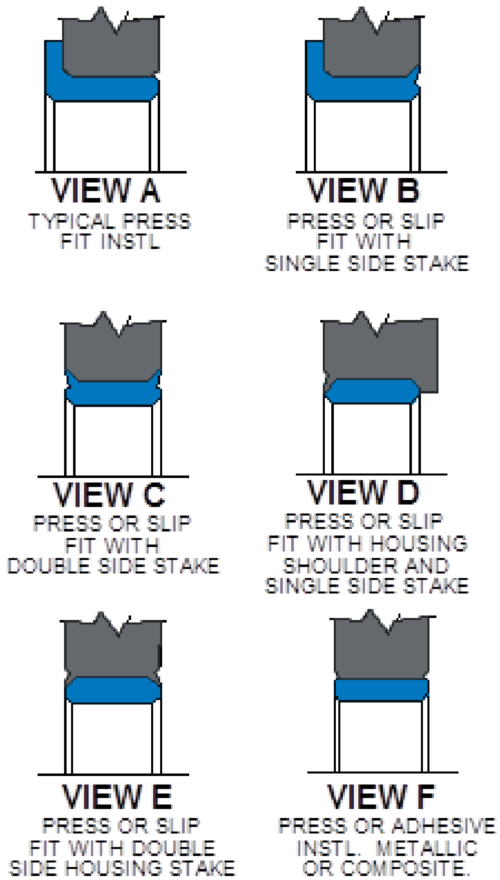

Figure 16
(Typical Journal Bearing Installation)

Note: When a bearing is retained axially within the housing, the fit between the bearing and housing can be either a slip or press fit. The choice depends upon, among other things, the load applied to the bearing and the possibility of it chucking or rotating within the housing. A slip fit should be considered if there is concern that the bore will reduce too much as a result of the fit and interfere with the motion of the shaft. **In the case of Kamatics lined bearings, this concern can be eliminated as the liner can be precisely machined after a press fit installation.**

View A, Figure 16 depicts the most common method of installing a flanged journal bearing with an interference fit. The designer is cautioned to remember that the interference will reduce the ID of the bearing. It is assumed that there is a thrust force in one direction only.

View B (Fig 16) depicts an installation similar to View A, however, with the addition of a swaging groove on the side opposite the flange. The lip of the groove is deformed into a chamfer in the housing, preventing possible migration of the bearing from the housing.

View C (Fig 16) depicts a non-flanged bearing installed with a swaging groove on both sides of the bearing. This will prevent the bearing from migrating out of the housing in either direction. Axial retention of the bearing is important especially if the shaft translates within the bore.

View D (Fig 16) depicts a non-flanged bearing retained by a housing shoulder on one side and a single-side housing stake on the other.

View E (Fig 16) depicts a bearing retained by two side housing staking grooves.

View F (Fig 16) depicts a bearing installed by either a press fit or a slip fit with a retaining adhesive to assist in maintaining position. The adhesive installation is very common with the use of composite bearings.

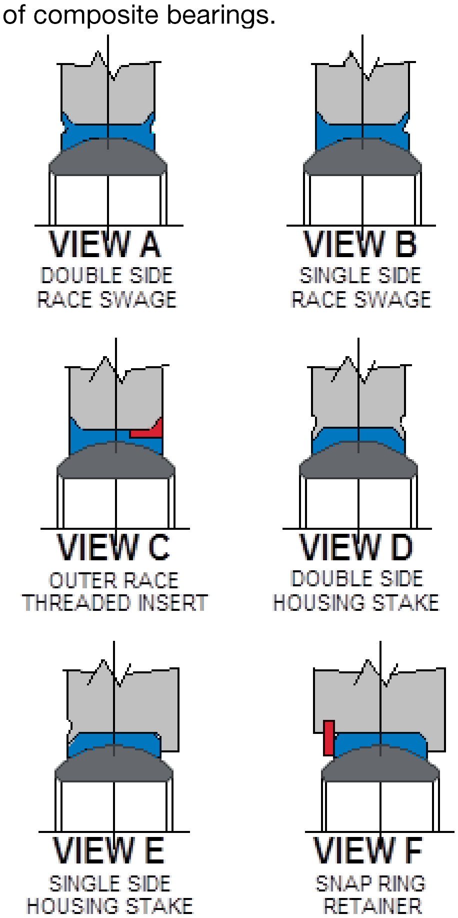

Figure 17
(Typical Spherical Bearing Installation)

Spherical Bearing Installation
There are various methods used to install spherical bearings. **Figure 17** illustrates some of the more common installations.
When installing a spherical bearing into its mating housing it is important to apply the force against the side face of the outer race and not against the ball. Pressing on the ball face may tend to "wedge" the ball into the outer race and affect the bearing torque. Similarly to journal bearings, the force to insert should be firm, steady and complete in one attempt. Use tooling to position the bearing before insertion if necessary to insure that the OD enters the housing properly. On those installations where the bearing is retained axially, the use of a small amount of lubricant to aid in the assembly process is acceptable. This is assuming it does not interfere with either the function of the bearing or any sealant application around the circumference of the joint after installation.

View A, Figure 17 depicts the more standard outer race double swaged groove installation. This method provides axial retention and allows multiple bearing replacements without damaging the housing. Roll or anvil swaging tools accomplish the swaging or deforming of the groove into the housing chamfers. Kamatics Tech Note 18 offers roll swaging information as well as instructions as to how to manufacture swaging tools.
View B (Fig 17) depicts another common installation where one side of the outer race has a pre-machined lip that nests into a housing chamfer and a groove on the opposite side to be swaged into a housing chamfer. This method assists in accurately positioning the bearing in the axial direction and requires only one swaging operation.

View C (Fig 17) depicts an installation where the bearing is captured in a housing by a pre-machined lip on one side and a removable threaded insert on the other. The insert is retained within the bearing via a nylon plug, or similar, that is deformed into the threads during assembly. This design is used for those applications where the bearing may have to be removed on site where the more normal swaging is difficult or impossible.

View D (Fig 17) shows an installation where the bearing is retained within the housing with a line of housing stakes around both sides of the bearing. This type of installation should be used only when absolutely necessary. Cost may be a driver for this type of installation. Generally, three or four stakes on each side are required for low-load non-critical applications. The major problem with this option is that the housing is damaged during the staking operation and great care must be taken so that the bearing is not deformed and unnecessarily tightened.

View E (Fig 17) depicts an installation similar to View D except only one line of housing stakes is used along with a housing shoulder. This type of installation does not provide the same ease of bearing replacement that View F does and damage occurs to the housing during each installation.

View F (Fig 17) depicts an installation where a shoulder on one side and a snap ring on the other retain the bearing. This type of installation is used when it may be necessary to remove the bearing and swaging or staking is not feasible. The snap ring is easily removed and allows replacement of the bearing.

Track / Cam Roller Installation
There are various methods used to install and attach a roller to structure. Figure 18 depicts some of the more common methods including Kamatics self-aligning roller bearings. A key to proper performance with track/cam rollers is the alignment of the roller OD with the track or cam. The typical non-self-aligning roller must be accurately positioned both relative to the track itself and in the direction of travel. Abnormally high contact stresses between the roller and track can occur if the roller axis is tilted resulting in point contact instead of line contact. If the roller is "skewed" relative to the direction of travel, outer race skidding and high thrust loads can occur. Fortunately, the Kamatics "KRP" roller has a significant thrust capacity that is virtually non-existent with the needle roller equivalent.

The Kamatics "KRP" self-aligning roller basically eliminates the concern for precision alignment both with respect to axis tilt and skewing. The outer race will "track" as required, following track wander and structure deflections or irregularities.

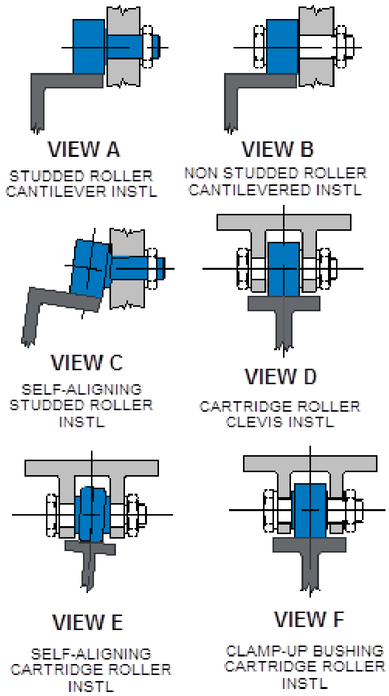

Figure 18
(Typical Track Roller/Cam Follower Installation)

View A, Figure 18 depicts a typical studded roller installation where the roller is attached to firm structure capable of reacting the moment loads applied during operation. The nut must be torqued to the point where the shoulder of the roller is firmly in contact with the structure.

View B (Fig 18) depicts an option to a studded roller where a standard cartridge roller is cantilevered off of structure and secured with a bolt and nut. There must be adequate room for the bolt head in the installation. A benefit of this installation is that it may be easier and timelier to obtain a bolt with the proper grip length than a studded roller with the grip needed.

View C (Fig 18) depicts a studded roller in a self-aligning configuration. It is installed exactly as any studded roller however, as shown, it has the unique capability of aligning to compensate for both track alignment and skew.

View D (Fig 18) depicts an installation of a cartridge (non-studded) roller in a clevis arrangement. In this installation, care in not putting too high a bending load on the clevis lugs is necessary. A better option to View D, if enough room exists, is shown in View F where no bending stress is put on the lugs.

View E (Fig 18) depicts a self-aligning cartridge roller. It is installed exactly as any non-studded roller, however, similar to the studded version shown in View C, it also has the capability of aligning to compensate for both track alignment and skew.

View F (Fig 18) depicts a cartridge roller installed in a clevis arrangement that employs the use of two clamp-up bushings. A flanged bushing is pressed into one lug. A second, non-flanged bushing is slip fit into the opposite lug and is of sufficient length to protrude beyond the lug when assembled. This protrusion insures that bolt clamp-up will not create bending forces in either lug. The load path is through the straight bush, through the bearing inner race, through the flanged bushing and finally through the lug opposite the straight bushing and reacted by the bolt head (or nut).

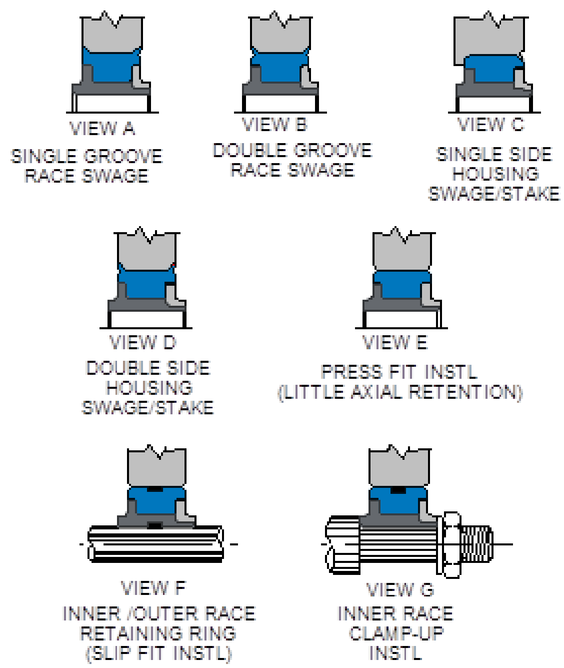

Figure 19
(Typical Pivot Bearing Installation)

View A, Figure 19 depicts a bearing installed with a press or slip fit. The outer race is incorporates an integral machined lip on one side and a swaging groove on the opposite. As in most installations of this type, including spherical bearings, the swaged lip is primarily for axial retention. It is not intended to prevent outer race rotation in the housing. If there is concern about bearing rotation in the housing, consider the use of a press fit in addition to the grooves or an adhesive. Suggested press fits are presented in this document. Bearings installed with swaging grooves can be replaced without damage to the housing.

View B (Fig 19) depicts a double outer race swaging groove installation. The bearing can be either a press or slip fit into the housing. All comments listed above for the View A installation are applicable to this installation.

View C (Fig 19) depicts a single housing swage/stake installation coupled with an integral housing shoulder. Similar to the previous two installations, the bearing may be either a press or slip fit. If intermittent line staking is chosen, the number of bearing replacements is normally limited to two. This installation provides thrust capability only in the direction of the shoulder.

Note: Intermittent line staking should be employed only in those cases where the staking is to contain the bearing during handling and assembly…not for any axial retention during operation.

View D (Fig 19) depicts a double housing swage/stake installation. Those comments listed for View C installations are also applicable here except there is no thrust capability in either direction.

View E (Fig 19) depicts an installation where the only axial retention device is the interference fit between the outer race and housing. The amount of retention is a function of the press fit. This type of installation should be used only after careful consideration.

View F (Fig 19) depicts an installation that uses a novel Kamatics innovation to retain a slip fit bearing. It incorporates the use of a polymer retaining ring in the outer race OD and/or the inner race ID. The polymer ring protrudes approximately .002 inches (0.05 mm) above the metallic surface, deforms and grips the mating surface during assembly. The slip fit shaft shown is typical of many torque tube bearing installations that had traditionally used ball bearings.

The polymer retaining ring should be considered for those applications where the possibility of unwanted relative motion exists between the outer race and housing or the inner race and shaft.

View G (Fig 19) depicts an installation that employs a familiar method on retaining the mating shaft to the inner race of the bearing. The shaft, with a “shoulder” or similar, is slipped into the bearing bore and secured to the inner race with the use of a nut or other threaded fastener. This approach can be used with any of the outer race retention methods previously shown.

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- Honing, Machining, Cleaning, and Measuring KAron and KAtherm
- Roller Swaging KAron/KAtherm Lined Self-Lubricated Spherical Bearings

Appendix B
- Self-Lubricating Liner Systems
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- KAron Fluid Compatibility
- KAron V Coefficient of Friction
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- KAron VS Datasheet
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- KFL-DM Datasheet
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- Surface Finish
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Appendix D
- P54 Wear Strip Datasheet
- KAron V Wear Strip Datasheet
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- Wear Strip Selection Guide
- Wear Strip Bonding Procedures

Appendix E
- Photographs of Kamatics Products

APPENDIX A

Honing, Machining, Cleaning & Measuring KAron and KAtherm

Honing:
The following information is supplied as an aid in KARON or KATHERM honing operations. A honing machine, Sunnen or similar, should be used and the finished ID be sized with standard GO\NO-GO plug gages. Tooling may be required to properly position the part being honed to insuring alignment, squareness, and/or position.

- **Stone -** Sunnen K6-A63 or K6-A65 or similar (280 grit medium hard aluminum oxide).
- **Speed -** 300 to1000 rpm, depending upon the diameter of the bushing being honed.
- **Coolant -** Sunnen MB30 (oil base) or similar.

After honing, ultrasonic clean the bushing in any of the cleaners noted below, to remove honing stone debris.

Machining:
The following information is supplied as an aid in KARON or KATHERM machining operations. The finished ID should be sized with standard GO\NO-GO plug gages. Tooling may be required to properly position the location of the ID.

- **Inserts -** Diamond inserts for best results, Carbide inserts acceptable. 0.030" nose radius minimum.
- **Speed -** 1000 surface feet per minute (300 meters per minute) minimum.
- **Depth of Cut -** as required.
- **Feed Rate -** 0.001/. 003 inches (0.025/0.075 mm) per revolution.
- **Coolant** – water-soluble coolant (if necessary).

Depending on size and the degree of accuracy required, special fixtures and/or holding devices may be required (as would be the case for machining any material). KAron is easily machined and therefore the use of a coolant is not necessary. The machining debris will be in the form of small chips and powder.

Cleaning:
Cleaning of the Kamatics bearings can be accomplished with practically any normal factory cleaner or solvent. Obviously those that do not leave a undesirable residue are preferred. Suggested is Turco 4215 alkaline detergent followed with a fresh water rinse, or Citrikleen XPC citric based solvent followed with a methanol rinse. Nitrosol, alcohol, acetone, and Tri-chlor 111 (when/if environmentally acceptable) can also be used. Avoid acids (hot or cold) and caustic "paint removers" as these can be a problem if left on the liner for an extended period of time (over 3 minutes).

Dimensional Inspection:
Dimensional inspection of KAron and KAtherm lined surfaces requires special consideration. Because or the fibrous nature of the material and its hardness relative to metals, we suggest the use of "GO-NO GO" gages when inspecting inside diameters. Light pressure on micrometer measurements on external surfaces readily measured with this type of instrument, should be used.

If conventional dial bore indicators are used, where there are several small pressure probes employed, it has been established that the reading on the gage should allow .00015 inches (0.0038 mm) for the probe penetration into the liner.

For example, if the high limit dimension on an inside diameter is 1.0000 inches (25.40 mm), a "dial bore" reading of 1.0003 inches (25.408 mm) would be an acceptable reading. The low limit value would be similarly affected

Roller Swaging KAron/KAtherm Lined Self-Lubricated Spherical Bearings

Scope
This document was created as a guide for users to properly install and retain Kamatics KAron®/KAtherm® lined self-lubricated spherical bearings into their assembly housings by utilizing the roller swage retention method.

Introduction
Proper installation and retention of Kamatics' self-lubricated spherical bearings is performed at Kamatics by utilizing either a bi-roller or a tri-roller swaging setup as described below. These processes of roller swaging require less force than anvil staking and allow for finer control of the swaging process. The basic procedure for proper retention of spherical bearings into their respective assembly housings utilizing the roller swage method involves design and assembly of the swage tool, upper and lower die design and selection, installation of the bearing into the housing, roller swaging, and breakaway torque measurement. Refer to the Kamatics Roll-Swage Bearing Installation Presentation for visual instruction.

Bi-Roller Roll Swage
The bi-roller roll swage method has been used for many years at Kamatics to properly retain spherical bearings in their assembly, such as a rod end banjo. This method allows the user to accommodate for various swage groove diameters/configurations. This is accomplished through spacers that can be added or removed depending on the size of the groove diameter. Figures 1 and 2 below illustrate the various components of the bi-roller setup.

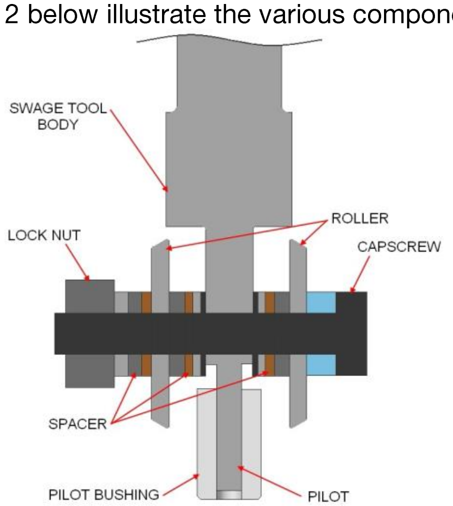


Figure 1 – Bi-roller swage tool schematic


Figure 2 – Bi-roller swage tool picture

Tri-Roller Roll Swage
The tri-roller roll swage method is a newer method used at Kamatics for bearing installation. This method involves using a roller body consisting of three roller wheels that rotate about the center axis. The benefit of using this method is that because there is more surface area contacting the swage, less force is required to roll the lip over the housing. Figures 3 and 4 below illustrate the various components of the tri-roller setup.

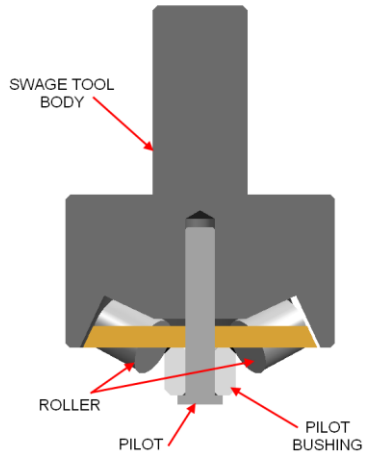


Figure 3 – Tri-roller swage tool schematic

Figure 4 – Tri-roller swage tool picture

Tools Needed

The following is a list of the tools needed to perform a roller swage procedure

- Drill Press (quill diameter > 2" & capable of 200lbf at the chuck)
- Arbor Press
- Wrenches – various sizes
- Lubrication with applicator brush
- Calipers
- Clean shop rags
- Upper die – Steel, Rc 40 MIN
- Lower die – Steel, Rc 40 MIN
- Rollers (2) – Tool Steel, Rc 55 MIN
- Pilot Bushing – Acetal Resin, PTFE, nylon, etc.
- Swage tool (bi-roller or tri-roller) – Tool Steel, Rc 40 MIN
- Spacers – various sizes, Steel, Rc 25 MIN
- Cap screw - .250 dia close tolerance, hardened, Rc 35 MIN
- Nut - .250 thread, self-locking
- Gloves (optional)
- Air supply
- Torque gage
- Torque fixture
- Wire feeler gage
- Double-sided tape

Measurements

In order to obtain the proper setup, a few measurements need to be taken. Figure 5 depicts the required dimensions of the spherical bearing needed for measurement. These measurements may be taken using a set of calibrated calipers while also verifying dimensions on the drawing for reference.

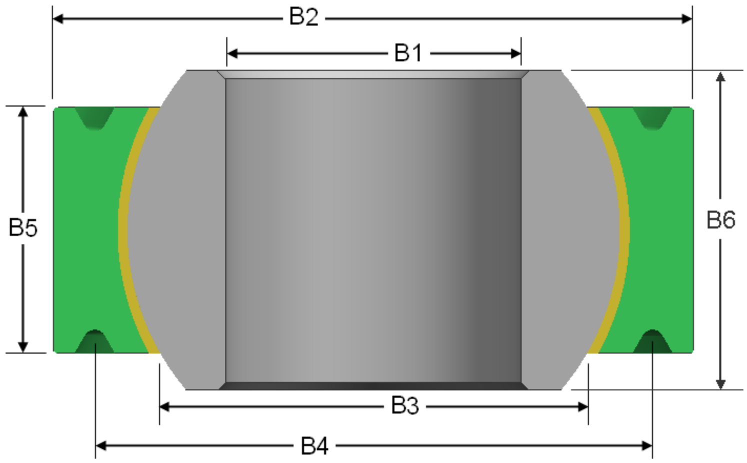
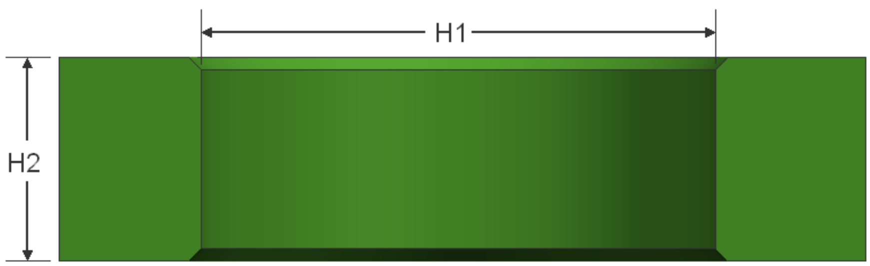


Figure 5 – Required spherical bearing measurements

where: B1 – Spherical bearing bore diameter
B2 – Spherical bearing outer diameter
B3 – Spherical bearing window diameter
B4 – Spherical bearing swage groove diameter
B5 – Spherical bearing race width
B6 – Spherical bearing ball width

Figure 6 depicts the required dimensions of the housing needed for measurement.



where: H1 – Housing bore diameter
H2 – Housing width

These measurements will be used to properly size the upper/lower die, bi-roller swage tool body, swage tool roller diameter, and swage tool spacer thickness.

Design and Assembly of Roller Swage Tool (Bi-Roller)

This section may be skipped if the tri-roller swage tool is to be used. As shown above in Figure 1, the components that make up the bi-roller swage tool consist of the swage tool body, cap screw, lock nut, spacers, rollers, and pilot bushing. Each part must be properly selected based on the size of the spherical bearing to be installed. The first component to select is the swage tool body. Figure 7 below shows the important geometry of the swage tool.

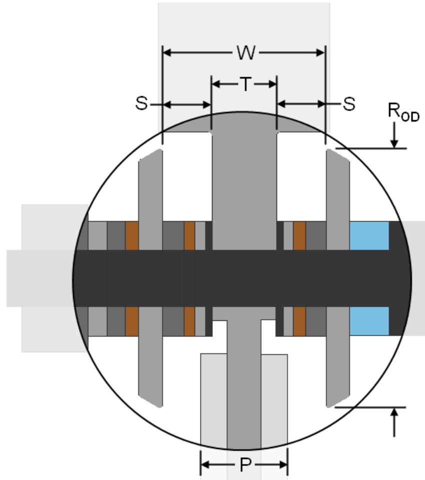


Figure 7 – Swage tool body spacing

W – max swage groove diameter + .005”	W = max B4 + .005"
T – swage groove tool width	T♠ > S
S – spacer width	S = ½ * (W-T)
R_{OD} – roller diameter	R_{OD}♠ < 1.25*B2
P – pilot bushing outer diameter	(B1 - .005”) < P < B1

♠ *Typically within .010 - .020”*

Kamatics houses incremental spacer thicknesses. For example, if the S dimension required was .055”, the user could select a .025” spacer and a .030” spacer, or a .015” spacer and a .040” spacer, or any combination to arrive at a combined thickness of .055”.

Figure 8 below depicts commonly used pilot bushings and a variety of spacers sorted by thickness used by the Kamatics spherical manufacturing group.

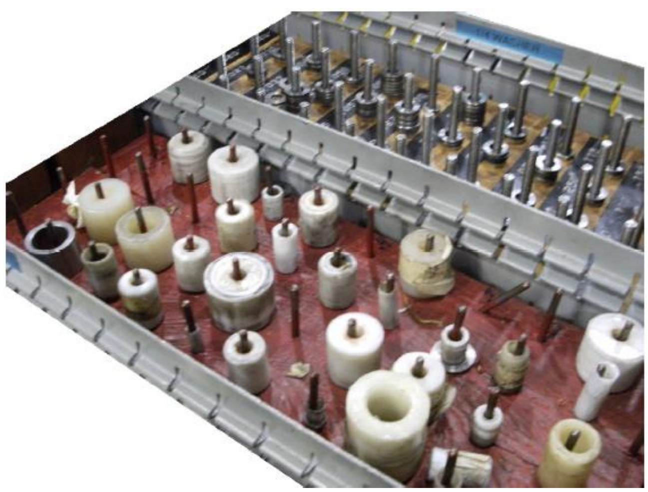


Figure 8 – Commonly used pilot bushings and spacers

Organizing the spacers in this way makes it easy and efficient to find the combination of spacers to obtain the proper thickness S for the swage tool.

The R_{OD} dimension represents the outer diameter of the roller. This R dimension is important because if the spherical to be swaged is small in diameter, using a large roller could result in galling on the edges of the swage groove. To correctly size the roller, the R dimension should be no larger than 1.25*spherical OD. The R dimension on each of the (2) required rollers must also be within .001” of each other. Figure 9 below shows the important geometry of the roller.

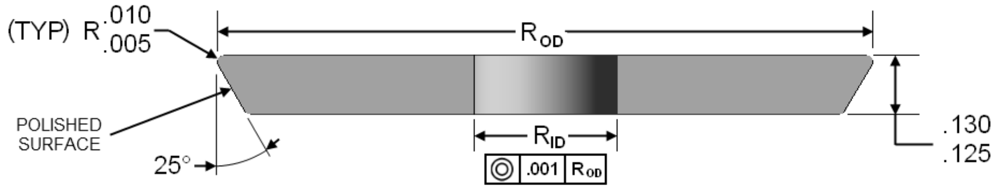


Figure 9 – Roller cross section showing important dimensions

where: R_{OD} – Roller outer diameter
R_{ID} – Roller bore

The pilot bushing diameter, designated by the letter P, should be a slip fit with the bore of the bearing. This P dimension should be no more than .005” less than the spherical bearing bore diameter. The pilot bushing is pressed over the pilot shaft of the swage tool.

Assembly of the swage tool could begin after the user has selected the proper swage tool body, the correct configuration of spacers for each side, the proper rollers, and the proper pilot bushing for the bearing. Figures 10 and 11 below show the correct order of operations when assembling the swage tool and the assembled swage tool, respectively.

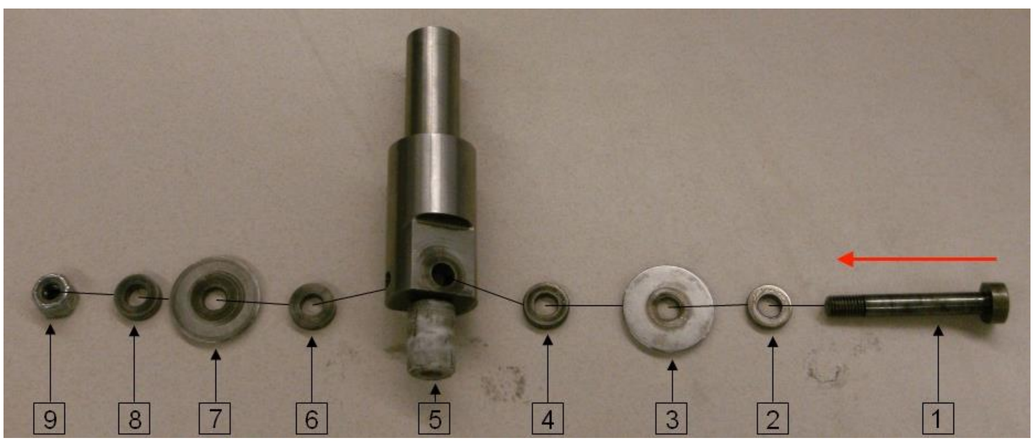


Figure 10 – Individual components order of operations

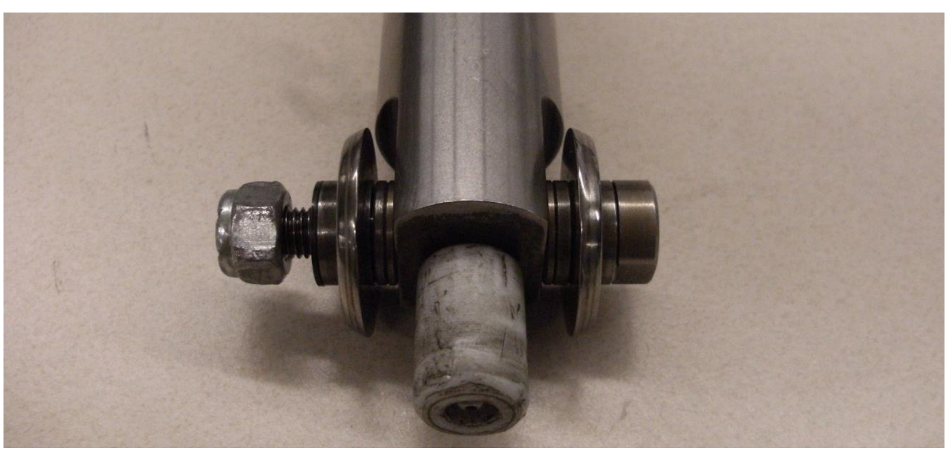


Figure 11 – Assembled swage tool

Note: Spacer #2 and #8 shown above must be selected such that the thread on the cap screw allows for positive clamp-up of the nut against the spacer. See Figure 12 below for visual.

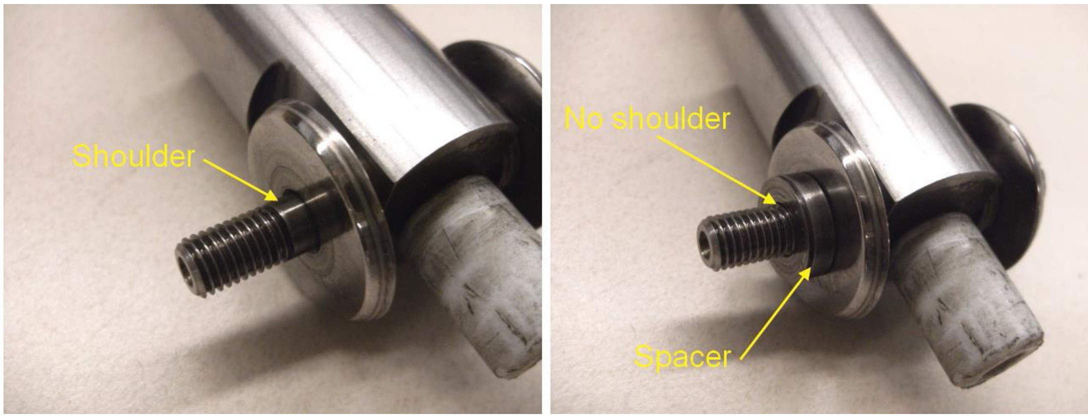


Figure 12 – Positive clamp-up

In order to properly torque the nut, tighten the nut on the thread until it is snug against the last spacer. Once the nut is snug, slowly back off the nut using the wrench while simultaneously trying to rotate the rollers. When the rollers start to rotate freely without binding, the adjustment is complete. This marks the completion of the bi-roller swage tool.

Design of Upper and Lower Die Tools

Depending on the spherical size, certain dies are used when installing the spherical bearing into its mating house. The two types of dies used for this installation include an upper and lower die. The designations “upper” and “lower” are relative terms associated with their position on the arbor press. The lower die is fixed on the base plate while the upper die is fixed to the ram using double-sided tape. Figure 13 below shows a picture of the arbor press with the upper and lower dies and their relative positions on the arbor press.

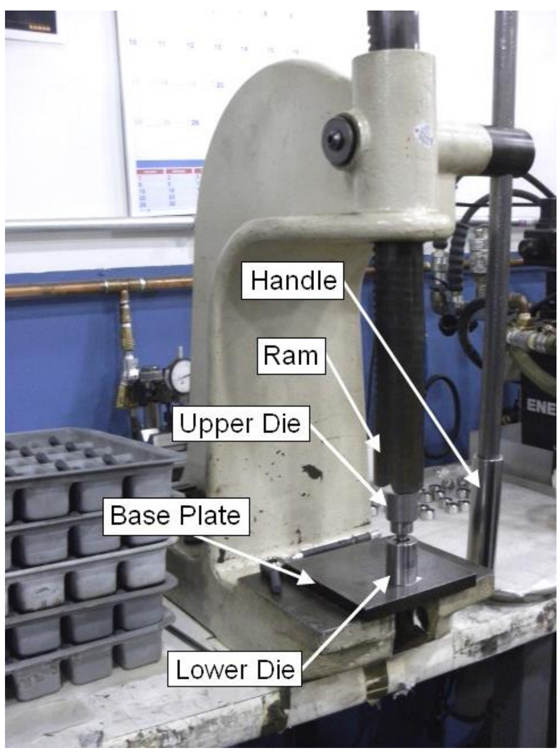
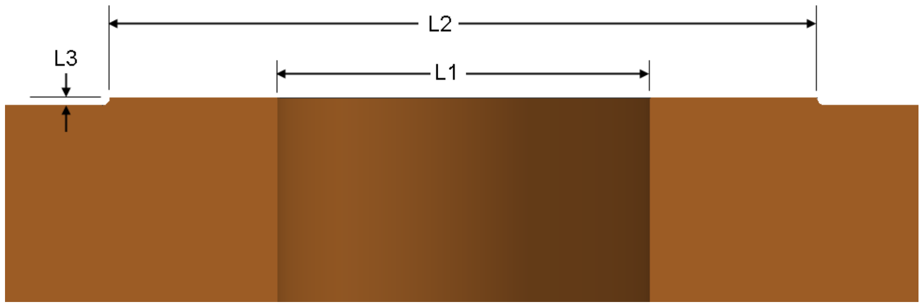


Figure 13 – Upper and Lower Die positions on arbor press

Lower Die Design

The lower die must be designed such that the spherical bearing is properly located within the housing width while also being large enough clear the ball of the bearing within the bore of the die. Figure 14 shows a cross section of the lower die.

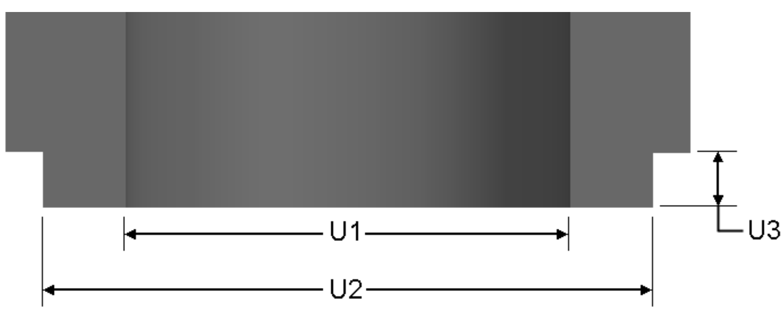


L1 – Lower die bore diameter	L1♦ > B3
L2 – Lower die step diameter	L2♦ < H1
L3 – Lower die step height	L3 = ½ * (H2 – B5) + .005”

In referencing the measurements taken from the spherical bearing, the bore diameter of the lower die (L1) must be larger than the window diameter (B3) to prevent any loading on the ball during installation. The lower die step diameter (L2) must be smaller than the housing bore diameter (H1). The lower die step height (L3) is the resultant of half of the difference between the housing width and the spherical bearing race width.

Upper Die Design

The upper die must also be designed to properly install the spherical bearing into the housing. Figure 15 below shows a cross section of the upper die.



U1 – Upper die bore diameter	U1♦ > B3
U2 – Upper die step diameter	U2♦ < H1
U3 – Upper die step height	U3♠ > ½ * (B6 – B5)

♦ Typically within .005 - .010”
♠ Typically within .010 - .020”

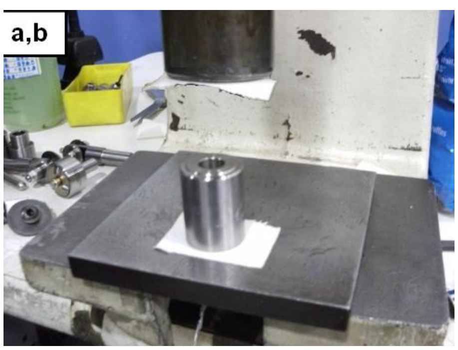
In referencing the measurements taken from the spherical bearing, the bore diameter of the upper die (U1) must be larger than the window diameter (B3) to prevent any loading on the ball during installation. The upper die step diameter (U2) must be smaller than the housing bore diameter (H1). The upper die step height (U3) must be greater than half of the difference between the spherical bearing ball width and the spherical bearing race width.

Once the swage tool has been designed and assembled and the upper and lower dies have been properly sized, the bearings are ready to be installed into their housings.

Bearing Installation into Assembly Housing

The following step-by-step procedure provides the instructions needed to successfully install KAron-lined self-lubricated spherical bearings into their assembly housing in a shop environment. While installations of KAron-lined self-lubricated spherical bearings in housings which are mounted on an aircraft require modified versions of the roller swaging tool, the basic procedure is the same.

a) Apply double-sided tape to the base plate and ram of the arbor press.
b) Secure the lower die onto the arbor press using double-sided tape.
c) Apply the specified installation finish (primer, sealant, lubricant, etc.) to the ID of the housing and the OD of the spherical bearing.
d) Place the housing on top of the lower die.
e) Place the spherical on top of the housing oriented such that it is concentric with the housing.
f) Place upper die on top of spherical.
g) Line up the lower die, housing, spherical bearing, and upper die such that each centerline is concentric to one another.
h) Slowly lower ram until it connects with the bottom of the upper die. The upper die will adhere to the ram via the double-sided tape.
i) Gradually apply even pressure on the handle until the bearing slides into the housing. Installation is complete when the bearing bottoms out on the lower die step.
j) Remove the bearing assembly from the arbor press and remove any excess installation finish. Minimize the amount of grease or other lubricants such that no contamination could enter into the bearing surfaces. Because lubricants can trap dust and other contamination, they should be removed from and KAron lined surface.
k) Inspect the installation for completeness. The bearing should be located within the center of the housing, or as specified on the drawing.
l) In the event that multiple bearings need to be installed, continue this process from step "c" until the remained of the spherical bearings have been properly installed into their housings. This will reduce processing time by only requiring one setup to be performed.


a,b


c


d,e,f,g,h


i

Once the bearing(s) has/have been installed into the housing(s), the roller swaging procedure can be performed.

Roll-Swage of Bearing in Housing

The following step-by-step procedure provides the instructions needed to successfully retain KAron/KAtherm-lined self-lubricated spherical bearings into their assembly housing in a shop environment using the roll-swage method. The bi-roller or tri-roller swage tool can be used interchangeably in this step. The bi-roller swage tool was used in this technical note for illustration purposes only.

a) Install roller swage tool into the chuck of the drill press and tighten using the proper chuck key.
b) Take the lower die from the arbor press base plate, remove the double-sided tape, and install the lower die into the air chuck on the base of the drill press. Aim air supply nozzle towards the swage tool – bearing interface. The air supply is required to evacuate any debris from the swage interface.
c) Adjust the spindle speed of the drill press according to the following rules:
    i. For bearings with bore diameters less than 1”, set spindle speed to 80 RPM
    ii. For bearings with bore diameters greater than 1”, set spindle speed to (80 / bore diameter) RPM (*Ex: bore diameter of 2” will yield 80/2 = 40 RPM spindle speed*)
d) Turn ON the drill press and air supply
e) Apply small amount of lubricant to the swage groove on bearing assembly to prevent galling during swage process.
f) Slide bearing assembly up pilot bushing on swage tool and adjust until the rollers are riding in the groove of the bearing. This step makes it easy to orient the ball in the housing just prior to swaging.
g) While holding bearing assembly up against the rollers, lower drill press until the bearing assembly contacts the lower die.
h) Apply increasing amounts of pressure to the drill press handle in small increments until the swage lip is rolled over onto the housing chamfer. If the swage has not been properly accomplished after (2) attempts, add a total of .005” between the rollers by varying the space configuration and repeat swage process. *NOTE*: Do not let the rollers touch the bottom or inner face of the swage groove in the bearing outer race. This can cause damage to the bearing and swage tool and/or binding of the bearing to the extent that the ball no longer rotates in the housing.
i) Remove bearing assembly from the drill press. Clean excess lubricant from the bearing with a rag wet with a small amount of methyl ethyl ketone, acetone, or similar solvent. Protect the inner race from the solvent and all lubricants during cleaning.
j) Visually inspect swage and use the .005” wire feeler gage to determine if swage is complete. *NOTE*: Feeler gage should NOT be able to be inserted into the bearing-housing interface. Refer to MIL-STD-1599 Requirement 202, Para. 6 for installation and subsequent inspection of installed bearings.

k) Continue to swage the remainder of bearing assemblies until the entire lot has been swaged on one side. After each assembly has been inspected, group the parts by placing them with the un-swaged side face up.

l) After swaging the first side, remove the double-sided tape from the upper die on the arbor press ram and replace the lower die in the air chuck with the upper die. The upper die is used to process the second side swage on each assembly.

m) Following the process above, roll-swage the second side of all the bearing assemblies.

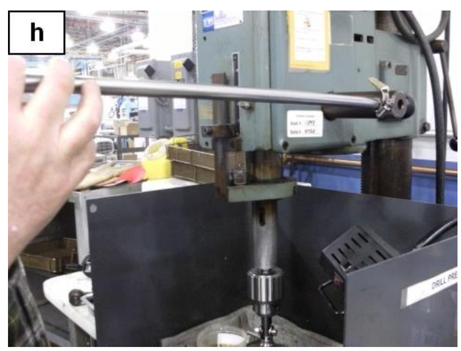

a

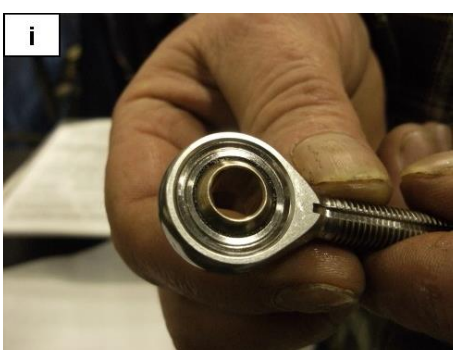

b


c,d

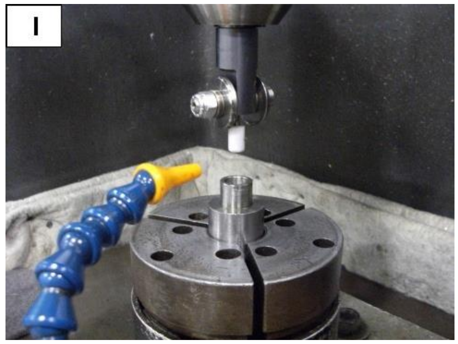

e


f,g


h


i


j



Once all of the bearing assemblies have been properly swaged on both sides, the air supply and drill press could be switched OFF.

No-Load Breakaway Torque Test

Before the bearing assemblies leave the manufacturing area, the no-load breakaway torque parameter is tested to make sure it complies with the engineering drawing. Unless otherwise specified by the overhaul instructions or on an assembly drawing, the no-load breakaway torque of the installed Kamatics lined spherical bearing must not be more than two times the uninstalled maximum breakaway torque specified in the bearing specification or standard. In order to check this parameter, the bearing assembly is installed into the torque fixture shown in Figure 16.

This torque fixture allows the housing of the bearing assembly to rotate independently of the ball of the spherical bearing. The torque fixture clamps up on the faces of the spherical ball. This fixture style can be adapted to many different sizes by adjusting the two jam nuts on the cap screw.

In order to find the torque of the bearing, insert the torque fixture into the torque gage, hold the torque gage firmly in one hand, and rotate the housing as shown in Figure 17 below.

Figure 16 – Bearing torque fixture

Figure 17 – Torque gage measurement

The gage needle should increase to a high value, then drop as the bearing rotates. This difference between static and dynamic friction is normal. The high value is considered the value for the no-load breakaway torque. Rotate the housing in both directions. Verify the measured value with the engineering drawing.

Pushout-Testing

If the customer requires that a push-out test be performed on the bearing following assembly to determine the integrity of the roller swage process, please contact the Kamatics engineering departments for testing methods and procedures.

APPENDIX B

TABLE 1
Self-Lubricating Liner Systems

Liner		Friction	Load Capacity	Surface Speed	Industry Specification(s)	Applicable Datasheet	Typical Applications
KAron B	Very High		X		SAE AS81820 SAE AS81934 BMS-39	175	Aircraft controls, landing gear, up-locks and othery highly loaded linkages, jet engine controls
	High						
	Moderate	X		X			
	Low						
	Very Low						
KAron V	Very High				SAE AS8943	174	Track rollers, marine & naval applications, Kaplan hubs & other hydro applications, shock struts & other landing gear applications
	High		X				
	Moderate			X			
	Low	X					
	Very Low						
KAron VS	Very High				EN4540	150	Aircraft flight controls, spherical bearings, high vibration applications, lightly loaded applications
	High						
	Moderate			X			
	Low		X				
	Very Low	X					
KAron F	Very High					107	Spherical bearings, track rollers, cam followers
	High						
	Moderate		X	X			
	Low						
	Very Low	X					
KAron BX	Very High		X		SAE AS81820 Type A	199	Motorsport suspension bearings, aircraft flight controls, landing gear joints and shock struts, fuel controls/pumps
	High						
	Moderate			X			
	Low	X					
	Very Low						
KAtherm T87	Very High			X	SAE AS81819 (Pending)	96	Engine linkages, thrust reversers, helicopter rotor controls
	High						
	Moderate	X	X				
	Low						
	Very Low						

NOTE: Kamatics also produces a variety of low to high temperature materials for wear strip, wear pads, wear bars, and bumper pad applications. Contact Kamatics Corporation for more information.

Typical KAron Characteristics:

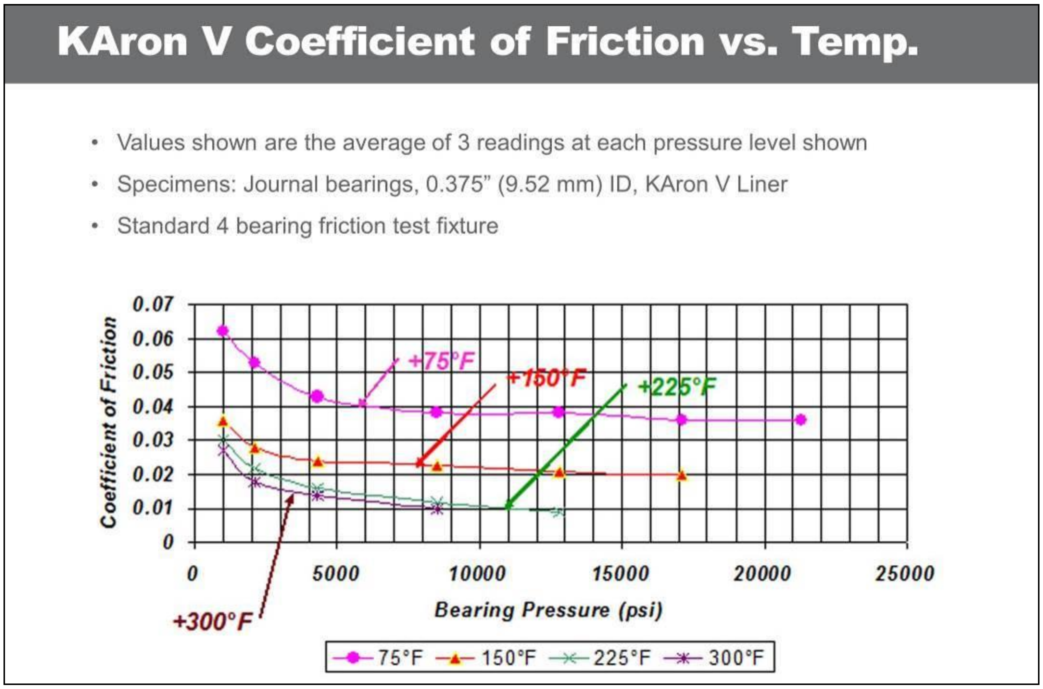
- Self-adhering – No secondary bonding
- Large thickness range – up to .060"
- Excellent fluid compatibility
- Excellent abrasion resistance
- Homogenous – uniform wear & friction
- Ability to refurbish components
- Machinable

The above list includes significant attributes for KAron liner systems. All KAron formulations are made from the same basic resin system, insuring consistent performance.

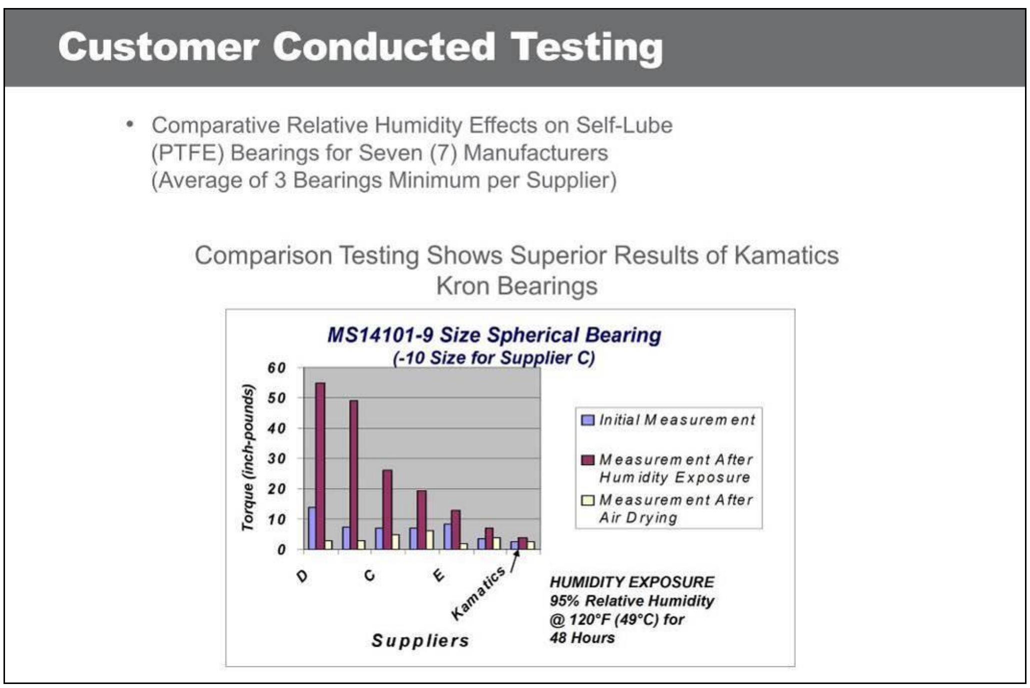
KAron Fluid Compatibility:

- Skydrol 500A/500B – Hydraulic Fluid
- MIL-H-5606 – Hydraulic Fluid
- MIL-PRF-83282 – Hydraulic Fluid
- MIL-PRF-7808 – Lubricating Oil
- MIL-L-2104 Grade 10 – Lubricating Oil
- MIL-L-23699 – Lubricating Oil
- MIL-A-8243 – Anti-Icing Fluid
- O-A-548 – Ethylene Glycol
- MIL-DTL-5624-JP-4, JP-5 & JP-8 Jet Fuel
- TT-S-735 Type VII – Standard Test Fluid
- MIL-L-25769 – Cleaning Compound
- TT-T-548 – Toluene
- TT-B-846 – Butyl Alcohol
- Water (both fresh & salt)
- Many other fluid…Contact Kamatics

It is important that a liner system be capable of operating in hostile environments. This includes the ability to function in various fluids without degrading, softening or swelling. The KAron liner system operates exceptionally in most industrial and aerospace fluids, including those listed above.



The slide above offers typical coefficient of friction values for the KAron V liner system at various temperatures and bearing pressures. If information as to the coefficients of other KAron liners is required, contact a Kamatics representative at 860-243-9704



The results shown above were obtained from testing conducted by a major aerospace company. It clearly shows that the KAron liner system was affected the least of the seven suppliers submitting specimens.

KAron B Data
Self-Lubricating Liner Material

1. Characteristics:

1.1. Nominal liner thickness: .010 to .015 in.(.25 to .38 mm), Max thickness .060 in.(1.52 mm)
1.2. Operating temperature range: -100° F to +450°F (-73 to +232°C)
1.3. Coefficient of friction range: .03 to .10, depending upon pressure, and velocity.
1.4. Compatible backing substrate materials: stainless steel, carbon steel, titanium, aluminum bronze, aluminum, phenolic, fiberglass, inconel and others.
1.5. Surface speeds to 3 fpm (0.9 m/min)

2. Physical Properties:

2.1. Specific gravity:	1.508
2.2. Density	1.505 gm/cc
2.3. Hardness	Rockwell M 90/100
2.4. Approximate Compression Modulus	7×10^5 psi (4,828 MPa)

3. Typical Load Carrying Capabilities:

3.1. Static Ultimate *	120,000 psi (827 MPa)
3.2. Static Limit **	80,000 psi (551 MPa)
3.3. Dynamic (max.)	50,000 psi (344 MPa)
3.4. Dynamic (continuous) ***	35,000 psi (241 MPa)

Notes: * Equivalent to 1.5 times the static limit load, local liner distress may occur.
** Maximum load which will result in a permanent set in the liner no greater than .003 (0.08mm) inches after the load is applied for 3 minutes.
*** .0045 inches (0.114 mm) maximum permitted wear after 25,000 cycles of oscillation at ± 25° at 10 cpm (8 rms mating surface, R_c50 min.). Typical liner thickness 0.012 in. (0.3 mm).

4. Applicable Specifications:

4.1 SAE AS-81820 – Bearings, plain, self-aligning, self-lubricating, low speed oscillation. (MS14101, MS14102, MS14103 & MS14104), (Kamatics KR-CNB, KR-CNGB, KR-CWB, KR-CWGB).
4.2 SAE AS-81934 – Bearings, sleeve, plain and flanged, self-lubricating (AS-81934/1-plain, AS-81934/2-flanged) (Kamatics KRJ-B & KRJ-UDB).

5. Typical Applications:

5.1. Airframe controls, flaps, etc., industrial applications requiring high load carrying capability and self-lubricating features.
5.2. The above information is to be considered as a guide only. Kamatics Corporation Engineering should be consulted for proposed applications.

KAron V Data

1. Characteristics:

1.1. Nominal liner thickness: .010 to .015 in.(.25 to .38 mm), Max thickness .060 in.(1.52 mm)
1.2. Operating temperature range: -100° F to +300°F (-73 to +149°C)
1.3. Coefficient of friction range: .03 to .08, depending upon pressure, and velocity.
1.4. Compatible backing substrate materials: stainless steel, carbon steel, titanium, aluminum bronze, aluminum, phenolic, fiberglass, inconel and others.
1.5. Surface speeds to 10 fpm (3.0 m/min)

2. Physical Properties:

2.1. Specific gravity:	1.363
2.2. Density	1.360 gm/cc
2.3. Hardness	Rockwell M 85/90
2.4. Approximate Compression Modulus	7 x 10^5 psi (4,828 MPa)

3. Typical Load Carrying Capabilities:

3.1. Static Ultimate *	100,000 psi (690 MPa)
3.2. Static Limit **	67,000 psi (462 MPa)
3.3. Dynamic (max.)	40,000 psi (276 MPa)
3.4. Dynamic (continuous) ***	30,000 psi (207 MPa)

Notes:
* Equivalent to 1.5 times the static limit load, local liner distress may occur.
** Maximum load which will result in a permanent set in the liner no greater than .004 (0.10mm) inches after the load is applied for 3 minutes.
*** .006 inches (0.152 mm) maximum permitted wear after 5,000 cycles of oscillation at ± 25° at 10 cpm (MIL-B-8943 requirement).
Typical liner thickness 0.012 in. (0.3 mm).

4. Applicable Specifications:

4.1. MIL-B-8943 – bearings, sleeve, plain and flanged, TFE lined (MS21240 & 21241) (Kamatics KRJ-V & KRJ-UDV).

5. Typical Applications:

5.1. Marine environment (including rudder and pintle bearings as well as hydrofoil strut pivot bearings), airframe controls, track and cam rollers and industrial applications requiring high load carrying capability and self-lubricating features.

KAron VS

1. Characteristics:

1.1. Description: A non-peelable, non-fabric, machineable homogeneous mixture of PTFE fibers and a polyester resin system that enable very low friction levels.
1.2. Nominal liner thickness: .010 to .015 in.(.25 to .38 mm), Max .060 in.(1.52 mm)
1.3. Operating temperature range: -100° F to +300°F (-73 to +149°C)
1.4. Coefficient of friction range: .02 to .05, depending upon pressure, and velocity.
1.5. Compatible backing substrate materials: stainless steel, carbon steel, titanium, aluminum, nickel alloys, composites.
1.6. Surface speeds to 10 fpm (3.0 m/min)

2. Physical Properties:

2.1. Density	1.56 gm/cc
2.2. Hardness	Rockwell 15X 88
2.3. Compression Modulus	3.1 x 10^5 psi (2,137 MPa)

3. Typical Load Carrying Capabilities:

3.1. Static Ultimate *	80,000 psi (551 MPa)
3.2. Static Limit **	50,000 psi (345 MPa)
3.3. Dynamic (max.)	25,000 psi (172 MPa)
3.4. Dynamic (continuous) ***	15,000 psi (103 MPa)

Notes:
* Equivalent to 1.5 times the static limit load, local liner distress may occur. Typical liner thickness 0.012 in. (0.3 mm).
** Maximum load which will result in a permanent set in the liner no greater than .004 (0.10mm) inches after the load is applied for 3 minutes. Typical liner thickness 0.012 in. (0.3 mm).
*** .006 inches (0.152 mm) maximum permitted wear after 5,000 cycles of oscillation at ± 25° at 10 cpm (MIL-B-8943 requirement). Typical liner thickness 0.012 in. (0.3 mm).

4. Fluid Compatibility:

4.1. Compatible with aircraft hydraulic fluids, lubricating oils, jet fuels, de-icing fluids, cleaning fluids, and water.

5. Typical Applications:

5.1. For bearing applications requiring an extremely low friction level such as flight controls, flap/slat track rollers, landing gear joints and shock strut bearings, fuel control/pumps, and mechanisms.

KAron® F

1. Characteristics:

1.1. Description: A non-peelable, non-fabric, matrix of PTFE fibers and a polyester resin system. KAron® F also employs an enriched surface of 100% PTFE that enable very low friction levels.
1.2. Nominal liner thickness: .010 to .015 in (.25 to .38 mm), Max .032 in.(0.81 mm)
1.3. Operating temperature range: -100° F to +250°F (-73 to +121°C)
1.4. Coefficient of friction range: .02 to .05, depending upon pressure, and velocity. *Example*: Ambient Coefficient of friction is approximately 0.03 under 10000 psi (69 MPa) and uncontaminated.
1.5. Compatible backing substrate materials: stainless steel, carbon steel, titanium, aluminum, nickel alloys, and composites.
1.6. Surface speeds to 10 fpm (3.0 m/min)

2. Fluid Compatibility:

2.1. Compatible with aircraft hydraulic fluids, lubricating oils, fuel, and cleaning and de-icing fluids and water.

3. Load Carrying Capabilities:

3.1. Static Ultimate*	60,000 psi (414 MPa)*
3.2. Static Limit**	40,000 psi (276 MPa)**
3.3. Dynamic (maximum)	30,000 psi (207 MPa)
3.4. Dynamic (continuous)***	20,000 psi (138 MPa)***

* Equivalent to 1.5 times static limit load. Local distress may occur.

** Maximum load that will result in permanent set less than 0.002 in (0.05mm) after load is applied for 3 minutes.

*** 65,000 cycles [± 25° motion, 20,000 psi (138 MPa) pressure, dry, ambient temperature] for 0.0045 in (0.11 mm) liner wear.

4. Typical Applications:

4.1. For bearing applications requiring an extremely low friction level such as flap/slat track rollers, landing gear joints and shock strut bearings, fuel control/pumps, and mechanisms.

Due to its fibrous nature, Kamatics recommends the use of GO/NO-GO ring and plug gauges when measuring KAron F coated parts, as described in ARP 5448/9 Plug Gauging for Plain Bearings.

KAron BX
Self-Lubricating Liner Material

1. Characteristics:

1.1. Description: A non-peelable, non-fabric, machineable homogenous mixture of PTFE fibers and a polyester resin system that enables very low friction levels.
1.2. Operating temperature range: -100° F to +325°F (-73 to +162°C)
1.3. Coefficient of friction range: .02 - .12, depending upon pressure, area, temperature, and velocity.
1.4. Compatible backing substrate materials: stainless steel, carbon steel, titanium, aluminum, nickel alloys, composites.
1.5. Surface speeds to 10 fpm (3.0 m/min)

2. Physical Properties:

2.1. Density	1.505 gm/cc
2.2. Hardness	Rockwell M 90/100
2.3. Compression Modulus	7 x 10^5 psi (4,828 MPa)

3. Typical Load Carrying Capabilities:

3.1. Static Ultimate *	120,000 psi (827 MPa)
3.2. Static Limit **	80,000 psi (551 MPa)
3.3. Dynamic (continuous) ***	33,000 psi (227 MPa)

Notes:
* Equivalent to 1.5 times the static limit load, local liner distress may occur. Typical liner thickness 0.012 in. (0.3 mm).
** Maximum load which will result in a permanent set in the liner no greater than .003 inches (0.075 mm) after the load is applied for 3 minutes. Typical liner thickness 0.012 in. (0.3 mm).
*** .0045 inches (0.114 mm) maximum permitted wear after 100,000 cycles of oscillation at ± 25° at 10 cpm (SAE AS81820A requirement). Typical liner thickness 0.012 in. (0.3 mm).

4. Applicable Specifications:

4.1. Qualified to SAE AS81820 Type A

5. Typical Applications:

5.1. For spherical bearing applications requiring extended life, such as flight controls, landing gear joints and shock strut bearings, fuel control/pumps, and mechanisms.
5.2. The above information is to be considered as a guide only. Kamatics Engineering should be consulted for specific applications.

6. Fluid Compatibility:

6.1. Compatible with aircraft hydraulic fluids, lubricating oils, jet fuels, de-icing fluids, cleaning fluids, and water.

KAtherm T-87 Data
Self-Lubricating Liner Material

1. Characteristics:

1.1. Nominal liner thickness: .010 to .015 in.(.25 to .38 mm), Max .060 in.(1.52 mm)
1.2. Operating temperature range : -100° F to +500°F (-73°C to +260°C)
1.3. Coefficient of friction range: .02 to .11, depending upon temperature, pressure, and velocity.
1.4. Compatible backing substrate materials: stainless steel, titanium, aluminum, high nickel alloys, composites.
1.5. Surface speeds up to 30 fpm (9 m/min)

2. Physical Properties:

2.1. Specific Gravity	1.366
2.2. Density	1.37 gm/cc
2.3. Hardness	Rockwell M 80/90
2.4. Compression Modulus	125,000 psi (875 MPa) (.012 in. (.305 mm) liner on CRES)

3. Typical Load Carrying Capabilities:

3.1. Static Ultimate	45,000 psi (310 MPa)
3.2. Static Limit	30,000 psi (207 MPa)
3.3. Dynamic (max. @ 500°F)	20,000 psi (138 MPa)
3.4. Wear @ 500°F (260°C)	Less than .005” (0.127 mm) at 20,000 psi (138 MPa) ±25°, 20 cpm

4. Typical Applications:

4.1. Gas Turbine Engine variable stator vanes bushings; sync ring pads; engine control bearings, cam followers, and linkage; thrust reverser bearings, cam followers, and high temperature industrial bearings, cam followers and linkages. Also high speed oscillating applications on helicopters such as main/tail rotor pitch change, pitch link, and scissors link bearings.

KFL-DM

1. Description:

1.1. KFL-DM is a unique surface coating that provides durable, lubricious, low friction sliding performance. KFL-DM is a polymer based film coating impregnated with PTFE, and other special fillers.

2. Characteristics:

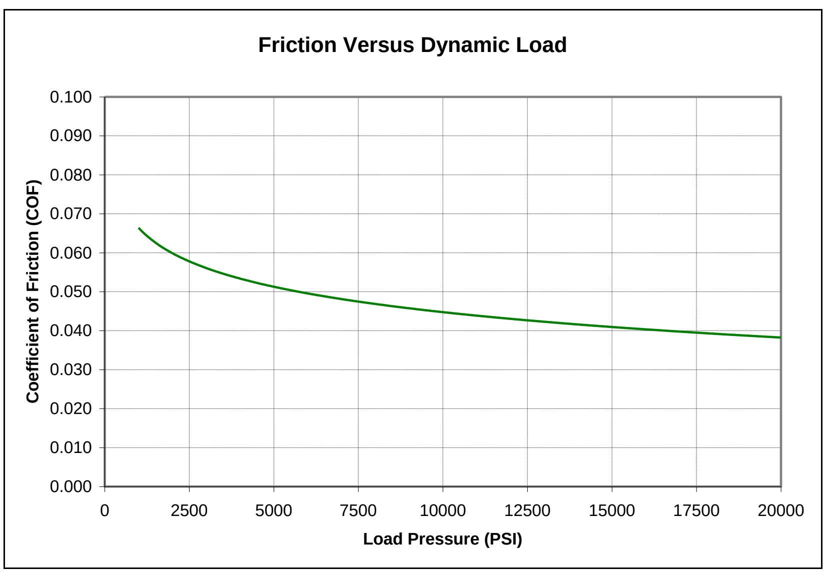
2.1. Thickness range: 0.001-in to 0.002-in (0.025 to 0.051 mm)
2.2. KFL-DM is a film coating which is directly adhered to a metal substrate and supplied in the as-applied condition (no machining).
2.3. KFL-DM can be applied to steel, stainless steel, aluminum, titanium, nickel-based alloys, and many other metals.

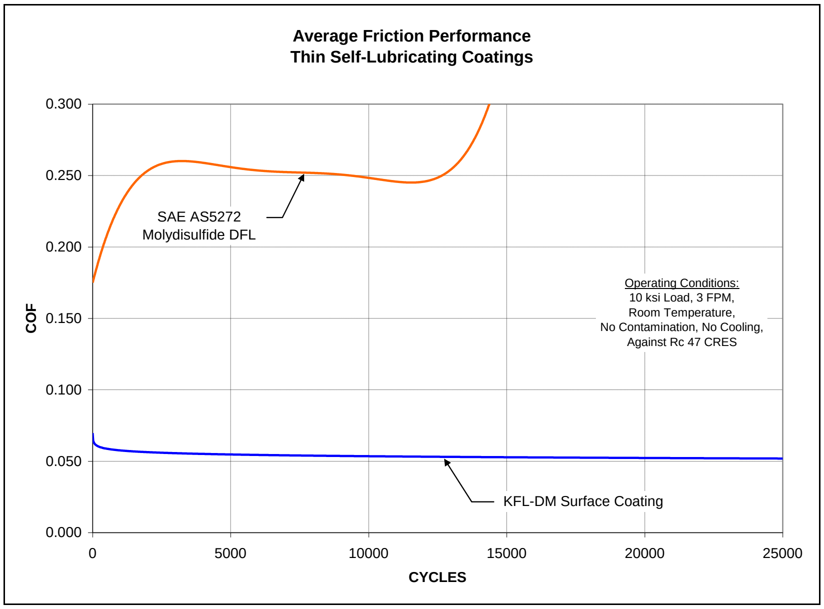
3. Physical Properties:

3.1.	Density	1.58 gm/cc
3.2.	Hardness	Rockwell M 80
3.3.	Color	Grey

4. Performance Capabilities:

4.1. Operating Temperature Range: -65°F to 350°F (-54°C to 177°C)
4.2. Max. Continuous Dynamic Pressure: 20,000 psi (138 MPa) at 0.5 fpm
4.3. Surface speeds to 10 fpm (3 m/min)
4.4. Coefficient of Friction: 0.04 -0.12 (Depending on Operating Conditions)



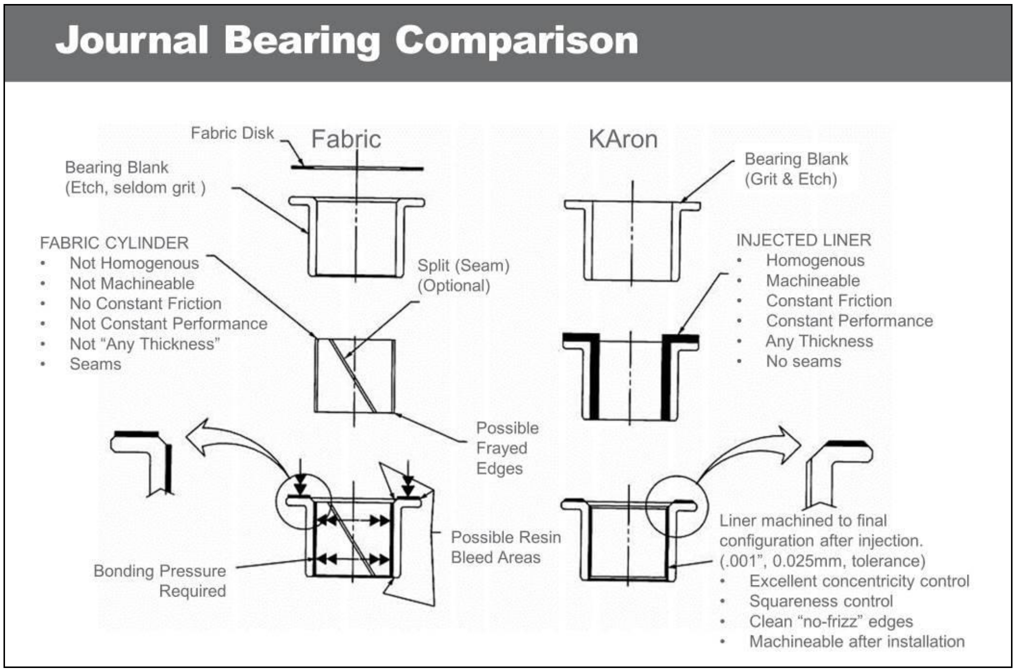


5. Fluid Compatibility:

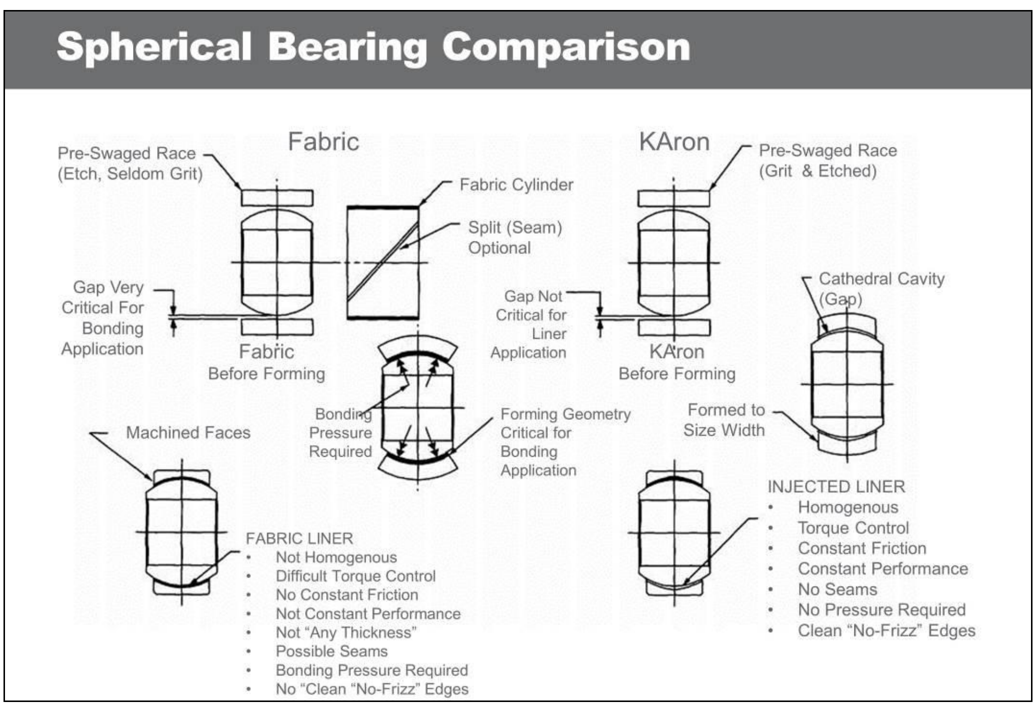
5.1. Compatible with aircraft hydraulic fluids, lubricating oils, jet fuels, de-icing fluids, cleaning fluids, and water.

6. Typical Applications:

6.1. For applications requiring a thin, low friction coating for metal surfaces that contact each other, and cause surface damage from rubbing and fretting.



The slide shown above graphically depicts the difference in the manufacture of a KAron lined journal bearing and that of a fabric lined journal bearing. It is readily apparent that a KAron lined bearing will allow trouble-free installation and provide constant operating performance. There is no the concern the realistic possibility of raised and/or frayed liner edges to interfere with the shaft/pin installation.



Similar to the slide above, this slide also depicts the differences in manufacture between a KAron lined spherical bearing and a fabric lined spherical bearing. The Kamatics cathedral cavity and no requirement for bonding pressure sets the KAron bearing apart

APPENDIX C

TABLE 2

Mating Bearing Surface	
Surface Finish	
Roughness-µin.	Life Factor
4-10 (0.1-.25 µm)	1.00
16 (0.4 µm)	.75
32 (0.8 µm)	.40
Surface Hardness	
Hardness Rc	Life Factor
50+	1.00
40	.60
30	.40

TABLE 3a (inch) Stainless Steel Journal Bearings

KAMATICS P/N	SAE AS81934 P/N	BEARING OD +0.0000, -0.0005	HOUSING ID +0.0010, -0.0000	MAX. SHAFT DIAMETER *
KRJ4-S	M81934/X-04C	0.3760	0.3743	0.2485
KRJ5-S	M81934/X-05C	0.4386	0.4369	0.3110
KRJ6-S	M81934/X-06C	0.5012	0.4995	0.3735
KRJ7-S	M81934/X-07C	0.5638	0.5621	0.4360
KRJ8-S	M81934/X-08C	0.6265	0.6248	0.4985
KRJ9-S	M81934/X-09C	0.6892	0.6875	0.5610
KRJ10-S	M81934/X-10C	0.8142	0.8125	0.6235
KRJ11-S	M81934/X-11C	0.8767	0.8750	0.6860
KRJ12-S	M81934/X-12C	0.9393	0.9376	0.7485
KRJ14-S	M81934/X-14C	1.0645	1.0628	0.8735
KRJ16-S	M81934/X-16C	1.1898	1.1881	0.9985
KRJ18-S	M81934/X-18C	1.3148	1.3131	1.1235
KRJ20-S	M81934/X-20C	1.4398	1.4381	1.2485
KRJ22-S	M81934/X-22C	1.5648	1.5631	1.3735
KRJ24-S	M81934/X-24C	1.7523	1.7503	1.4989
KRJ26-S	M81934/X-26C	1.8773	1.8753	1.6239
KRJ28-S	M81934/X-28C	2.0023	2.0003	1.7489
KRJ32-S	M81934/X-32C	2.2523	2.2503	1.9989

- *Maximum shaft diameter is based on 0.001 inch resultant clearance between the shaft OD and bearing ID after bearing installation in its housing.

TABLE 3b (millimeter) Stainless Steel Journal Bearings

KAMATICS P/N	SAE AS81934 P/N	BEARING OD +0.0000, -0.0127	HOUSING ID +0.0254, -0.0000	MAX. SHAFT DIAMETER
KRJ4-S	M81934/X-04C	9.5504	9.5072	6.3119
KRJ5-S	M81934/X-05C	11.1404	11.0973	7.8994
KRJ6-S	M81934/X-06C	12.7305	12.6873	9.4869
KRJ7-S	M81934/X-07C	14.3205	14.2773	11.0744
KRJ8-S	M81934/X-08C	15.9131	15.8699	12.6619
KRJ9-S	M81934/X-09C	17.5057	17.4625	14.2494
KRJ10-S	M81934/X-10C	20.6807	20.6375	15.8369
KRJ11-S	M81934/X-11C	22.2682	22.2250	17.4244
KRJ12-S	M81934/X-12C	23.8582	23.8150	19.0119
KRJ14-S	M81934/X-14C	27.0383	26.9951	22.1869
KRJ16-S	M81934/X-16C	30.2209	30.1777	25.3619
KRJ18-S	M81934/X-18C	33.3959	33.3527	28.5369
KRJ20-S	M81934/X-20C	36.5709	36.5277	31.7119
KRJ22-S	M81934/X-22C	39.7459	39.7027	34.8869
KRJ24-S	M81934/X-24C	44.5084	44.4576	38.0721
KRJ26-S	M81934/X-26C	47.6834	47.6326	41.2471
KRJ28-S	M81934/X-28C	50.8584	50.8076	44.4221
KRJ32-S	M81934/X-32C	57.2084	57.1576	50.7721

- *Maximum shaft diameter is based on 0.0254 millimeter resultant clearance between the shaft OD and bearing ID after bearing installation in its housing.

TABLE 4a (inch) Aluminum Alloy Journal Bearings

KAMATICS P/N	SAE AS81934 P/N	BEARING OD ±0.0005	HOUSING ID +0.0010, -0.0000	MAX. SHAFT DIAMETER *
KRJ4-Y	M81934/X-04A	0.3760	0.3748/0.3753	0.2485
KRJ5-Y	M81934/X-05A	0.4386	0.4374/0.4379	0.3110
KRJ6-Y	M81934/X-06A	0.5012	0.5000/0.5005	0.3735
KRJ7-Y	M81934/X-07A	0.5638	0.5626/0.5631	0.4360
KRJ8-Y	M81934/X-08A	0.6265	0.6253/0.6258	0.4985
KRJ9-Y	M81934/X-09A	0.6892	0.6880/0.6885	0.5610
KRJ10-Y	M81934/X-10A	0.8142	0.8130/0.8135	0.6235
KRJ11-Y	M81934/X-11A	0.8767	0.8755/0.8760	0.6860
KRJ12-Y	M81934/X-12A	0.9393	0.9381/0.9386	0.7485
KRJ14-Y	M81934/X-14A	1.0645	1.0628	0.8735
KRJ16-Y	M81934/X-16A	1.1898	1.1881	0.9983
KRJ18-Y	M81934/X-18A	1.3148	1.3131	1.1233
KRJ20-Y	M81934/X-20A	1.4398	1.4381	1.2483
KRJ22-Y	M81934/X-22A	1.5648	1.5631	1.3733
KRJ24-Y	M81934/X-24A	1.7523	1.7503	1.4983
KRJ26-Y	M81934/X-26A	1.8773	1.8753	1.6233
KRJ28-Y	M81934/X-28A	2.0023	2.0003	1.7483
KRJ32-Y	M81934/X-32A	2.2523	2.2503	1.9993

- *Maximum shaft diameter is based on 0.001 inch resultant clearance between the shaft OD and bearing ID after bearing installation in its housing.

TABLE 4b (millimeter) Aluminum Alloy Journal Bearings

KAMATICS P/N	SAE AS81934 P/N	BEARING OD ±0.0127	HOUSING ID +0.0254, -0.0000	MAX. SHAFT DIAMETER*
KRJ4-Y	M81934/X-04A	9.5504	9.5200/9.5326	6.3119
KRJ5-Y	M81934/X-05A	11.1404	11.1010/11.1227	7.8994
KRJ6-Y	M81934/X-06A	12.7305	12.7000/12.7127	9.4869
KRJ7-Y	M81934/X-07A	14.3205	14.2900/14.3027	11.0744
KRJ8-Y	M81934/X-08A	15.9131	15.8826/15.8953	12.6619
KRJ9-Y	M81934/X-09A	17.5057	17.4752/17.4879	14.2494
KRJ10-Y	M81934/X-10A	20.6807	20.6502/20.6629	15.8369
KRJ11-Y	M81934/X-11A	22.2682	22.2377/22.2504	17.4244
KRJ12-Y	M81934/X-12A	23.8582	23.8277/23.8404	19.0119
KRJ14-Y	M81934/X-14A	27.0383	26.9951	22.1869
KRJ16-Y	M81934/X-16A	30.2209	30.1777	25.3568
KRJ18-Y	M81934/X-18A	33.3959	33.3527	28.5318
KRJ20-Y	M81934/X-20A	36.5709	36.5277	31.7068
KRJ22-Y	M81934/X-22A	39.7459	39.7027	34.8818
KRJ24-Y	M81934/X-24A	44.5084	44.4576	38.0568
KRJ26-Y	M81934/X-26A	47.6834	47.6326	41.2318
KRJ28-Y	M81934/X-28A	50.8584	50.8076	44.4068
KRJ32-Y	M81934/X-32A	57.2084	57.1576	50.7822

- *Maximum shaft diameter is based on 0.0254 millimeter resultant clearance between the shaft OD and bearing ID after bearing installation in its housing.

TABLE 5a (inch) Spherical Bearings (Narrow Series)

KAMATICS P/N	SAE AS81820 P/N	Bearing OD +0.0000, -0.0005	Housing ID +0.0000, -0.0005	Housing Chamfer x 45°±5°(inches)	Recommended Housing Width +0.010, -0.000
KR3-CNG	MS14101-03	0.5625	0.5618	0.020-0.025	0.218
KR4-CNG	MS14101-04	0.6562	0.6555	0.020-0.025	0.250
KR5-CNG	MS14101-05	0.7500	0.7493	0.020-0.025	0.281
KR6-CNG	MS14101-06	0.8125	0.8118	0.020-0.025	0.312
KR7-CNG	MS14101-07	0.9062	0.9055	0.020-0.025	0.343
KR8-CNG	MS14101-08	1.0000	0.9993	0.040-0.045	0.390
KR9-CNG	MS14101-09	1.0937	1.0930	0.040-0.045	0.437
KR10-CNG	MS14101-10	1.1875	1.1868	0.040-0.045	0.500
KR12-CNG	MS14101-12	1.4375	1.4368	0.040-0.045	0.593
KR14-CNG	MS14101-14	1.5625	1.5618	0.040-0.045	0.703
KR16-CNG	MS14101-16	1.7500	1.7493	0.040-0.045	0.797
KR20-CNG	MS14101-20	2.0000	1.9993	0.040-0.045	0.942

TABLE 5b (millimeters) Spherical Bearings (Narrow Series)

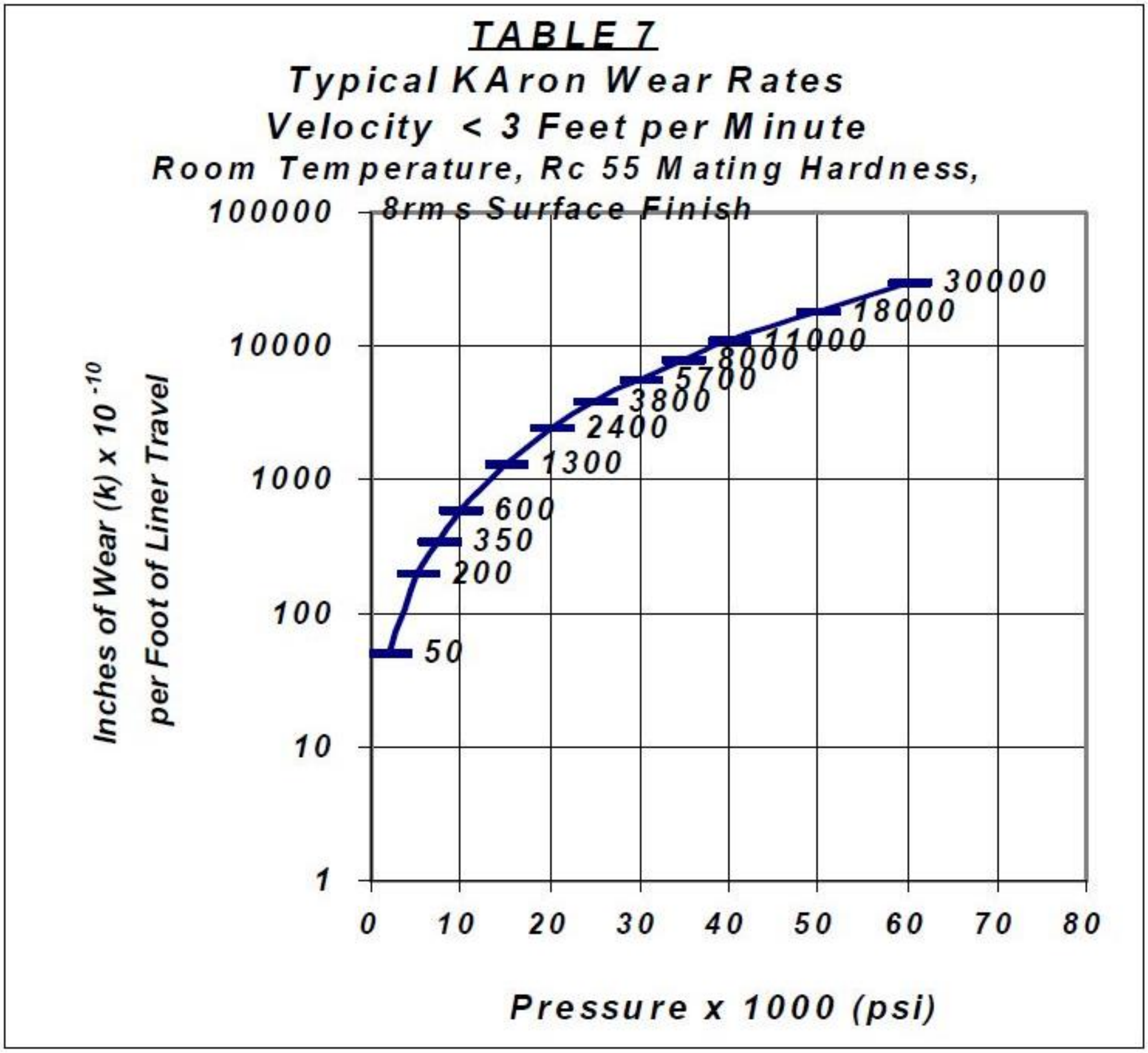
KAMATICS P/N	SAE AS81820 P/N	Bearing OD +0.0000, -0.0127	Housing ID +0.0000, -0.0127	Housing Chamfer x 45°±5°	Recommended Housing Width +0.250, -0.000
KR3-CNG	MS14101-03	14.2875	14.270	0.51-0.64	5.5372
KR4-CNG	MS14101-04	16.6675	16.650	0.51-0.64	6.3500
KR5-CNG	MS14101-05	19.0500	19.032	0.51-0.64	7.1374
KR6-CNG	MS14101-06	20.6375	20.620	0.51-0.64	7.9248
KR7-CNG	MS14101-07	23.0175	23.000	0.51-0.64	8.7122
KR8-CNG	MS14101-08	25.4000	25.382	1.000-1.140	9.9060
KR9-CNG	MS14101-09	27.7800	27.762	1.000-1.140	11.0998
KR10-CNG	MS14101-10	30.1625	30.145	1.000-1.140	12.7000
KR12-CNG	MS14101-12	36.5125	36.495	1.000-1.140	15.0622
KR14-CNG	MS14101-14	39.6875	39.670	1.000-1.140	17.8562
KR16-CNG	MS14101-16	44.4500	44.432	1.000-1.140	20.2438
KR20-CNG	MS14101-20	50.8000	50.782	1.000-1.140	23.9268

TABLE 6a (inch) Spherical Bearings (Wide Series)

KAMATICS P/N	SAE AS81820 P/N	Bearing OD +0.0000, -0.0005	Housing ID +0.0000, -0.0005	Housing Chamfer x 45°±5°	Recommended Housing Width +0.010, -0.000
KR3-CWG	MS14103-03	0.6250	0.6243	0.020-0.025	0.327
KR4-CWG	MS14103-04	0.6250	0.6243	0.020-0.025	0.327
KR5-CWG	MS14103-05	0.6875	0.6868	0.020-0.025	0.317
KR6-CWG	MS14103-06	0.8125	0.8118	0.020-0.025	0.406
KR7-CWG	MS14103-07	0.9375	0.9368	0.020-0.025	0.442
KR8-CWG	MS14103-08	1.0000	0.9993	0.020-0.025	0.505
KR9-CWG	MS14103-09	1.1250	1.1243	0.020-0.025	0.536
KR10-CWG	MS14103-10	1.1875	1.1868	0.020-0.025	0.567
KR12-CWG	MS14103-12	1.3750	1.3743	0.040-0.045	0.630
KR14-CWG	MS14103-14	1.6250	1.6243	0.040-0.045	0.755
KR16-CWG	MS14103-16	2.1250	2.1243	0.040-0.045	1.005
KR20-CWG	MS14103-20	2.3750	2.3743	0.040-0.045	1.130

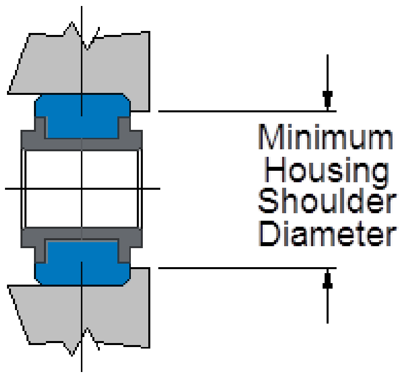
TABLE 6b (millimeters) Spherical Bearings (Wide Series)

KAMATICS P/N	SAE AS81820 P/N	Bearing OD +0.0000, -0.0127	Housing ID +0.0000, -0.0127	Housing Chamfer x 45°±5°	Recommended Housing Width +0.254, -0.000
KR3-CWG	MS14103-03	15.8750	15.857	0.051-0.064	8.306
KR4-CWG	MS14103-04	15.8750	15.857	0.051-0.064	8.306
KR5-CWG	MS14103-05	17.4625	17.445	0.051-0.064	8.052
KR6-CWG	MS14103-06	20.6375	20.620	0.051-0.064	10.312
KR7-CWG	MS14103-07	23.8125	23.795	0.051-0.064	11.227
KR8-CWG	MS14103-08	25.4000	25.382	0.051-0.064	12.827
KR9-CWG	MS14103-09	28.5750	28.557	0.051-0.064	13.614
KR10-CWG	MS14103-10	30.1625	30.145	0.051-0.064	14.402
KR12-CWG	MS14103-12	34.9250	34.907	1.000-1.140	16.002
KR14-CWG	MS14103-14	41.2750	41.257	1.000-1.140	19.177
KR16-CWG	MS14103-16	53.9750	53.957	1.000-1.140	25.527
KR20-CWG	MS14103-20	60.3250	60.307	1.000-1.140	28.702

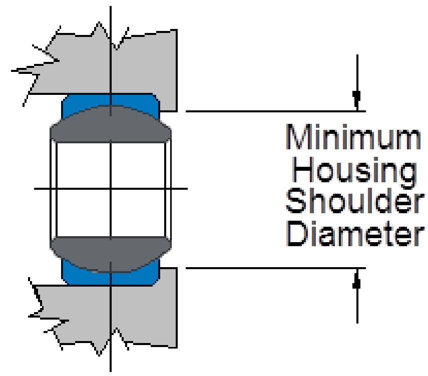


The values above are to be considered as a guide only for initial sizing of a bearing under consideration. Other contributing factors such as mating surfaces hardness, finish, contamination, temperature and type of bearing motion (oscillation, translation or rotation) have an effect on the amount of liner wear. After sizing the bearing, consult Kamatics engineering for review and comments.

TABLE 7a
Recommended Minimum Housing Shoulder Diameters (Inches)



"KRP" Design



Spherical Design

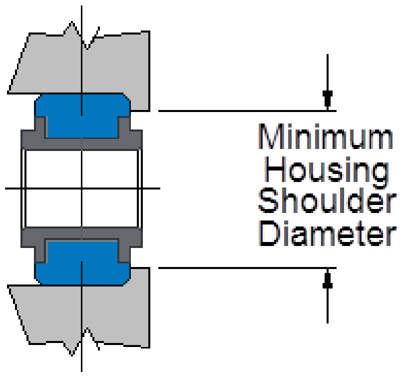
Bearing Number	Minimum Housing Shoulder Diameter
KRP3	.62
KRP4	.73
KRP5	1.01
KRP6	1.23
KRP8	1.45
KRP10	1.65
KRP3A	.52
KRP4A	.62
KRP5A	.68
KRP6A	.75
KRP8A	.98
KRP10A	1.21
KRP12A	1.46
KRP16A	1.76
KRP20A	2.03
KRP16B	1.59
KRP16BS	1.72
KRP21B	1.89
KRP23B	2.02
KRP25B	2.13
KRP29B	2.37
KRP33B	2.67
KRP37B	2.91
KRP47B	3.60
KRP49B	3.77
KRP49BK	3.69

Bearing Number	Minimum Housing Shoulder Diameter
KRP21BS	2.10
KRP23BS	2.16
KRP25BS	2.28
KRP29BS	2.54
KRP33BS	2.79
KRP37BS	3.04
KRP47BS	3.85
KRP48BS	3.97
KRP49BS	3.97
KRPB538	.92
KRPB539	1.04
KRPB540	1.16
KRPB541	1.36
KRPB542	1.60
KRPB543	1.84
KRPB544	2.12
KRPB545	2.43
KRPB546	2.68
KRPP3	.63
KRPP4	.72
KRPP5	1.08
KRPP6	1.25
KRPP8	1.47
KRPP10	1.64

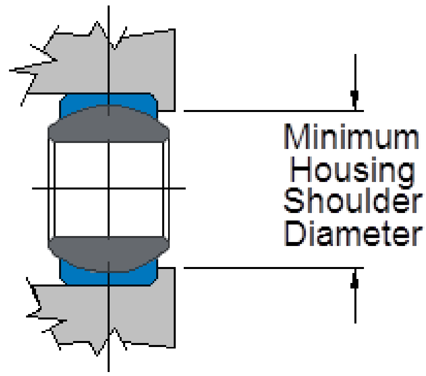
Bearing Number	Minimum Housing Shoulder Diameter
KR3CN	.39
KR4CN	.48
KR5CN	.53
KR6CN	.59
KR7CN	.64
KR8CN	.72
KR9CN	.80
KR10CN	.87
KR12CN	1.07
KR14CN	1.15
KR16CN	1.31
KR20CN	1.55
KR3CW	.46
KR4CW	.50
KR5CW	.54
KR6CW	.60
KR7CW	.69
KR8CW	.76
KR9CW	.89
KR10CW	.94
KR12CW	1.08
KR14CW	1.19
KR16CW	1.63
KR20CW	1.81

Bearing Number	Minimum Housing Shoulder Diameter
KR3CE	.43
KR4CE	.58
KR5CE	.58
KR6CE	.74
KR8CE	.96
KR10CE	1.16
KR12CE	1.27
KR14CE	1.72

TABLE 7b
Recommended Minimum Housing Shoulder Diameters
(Millimeters)



"KRP" Design



Spherical Design

Bearing Number	Minimum Housing Shoulder Diameter
KRP3	15.80
KRP4	18.59
KRP5	25.76
KRP6	31.34
KRP8	36.93
KRP10	41.81
KRP3A	13.21
KRP4A	15.75
KRP5A	17.38
KRP6A	19.16
KRP8A	24.80
KRP10A	30.84
KRP12A	37.19
KRP16A	44.81
KRP20A	51.46
KRP16B	40.46
KRP16BS	43.64
KRP21B	48.11
KRP23B	51.21
KRP25B	54.15
KRP29B	60.25
KRP33B	67.87
KRP37B	73.91
KRP47B	91.44
KRP49B	95.71
KRP49BK	93.78

Bearing Number	Minimum Housing Shoulder Diameter
KRP21BS	53.29
KRP23BS	54.74
KRP25BS	57.96
KRP29BS	64.40
KRP33BS	70.79
KRP37BS	77.19
KRP47BS	97.69
KRP48BS	100.89
KRP49BS	100.89
KRPB538	23.47
KRPB539	26.47
KRPB540	29.51
KRPB541	34.54
KRPB542	40.59
KRPB543	46.69
KRPB544	53.75
KRPB545	61.82
KRPB546	68.02
KRPP3	16.10
KRPP4	18.24
KRPP5	27.38
KRPP6	31.70
KRPP8	37.29
KRPP10	41.61

Bearing Number	Minimum Housing Shoulder Diameter
KR3CN	9.80
KR4CN	12.07
KR5CN	13.34
KR6CN	14.86
KR7CN	16.13
KR8CN	18.16
KR9CN	20.32
KR10CN	22.10
KR12CN	27.18
KR14CN	29.21
KR16CN	33.27
KR20CN	39.37
KR3CW	11.68
KR4CW	12.57
KR5CW	13.72
KR6CW	15.11
KR7CW	17.40
KR8CW	19.18
KR9CW	22.48
KR10CW	23.88
KR12CW	27.43
KR14CW	30.23
KR16CW	41.28
KR20CW	45.85

Bearing Number	Minimum Housing Shoulder Diameter
KR3CE	10.80
KR4CE	14.61
KR5CE	14.61
KR6CE	18.80
KR8CE	24.38
KR10CE	29.34
KR12CE	32.13
KR14CE	43.69

APPENDIX D

P54 WEAR STRIP MATERIALS PROPERTY DATA SHEET

Description:
Kamatics P54 Wear Strip material is a thin sheet self-lubricating bearing material engineered to provide exceptional wear and abrasion resistance. P54 is comprised of a resilient thermoset resin matrix with synthetic fibers in a laminate construction for strength and durability. As a wear strip, it is designed to be bonded onto surfaces which are subjected to light to medium duty rubbing pressure, or as a fretting resistant barrier.

Typical Applications:
P54 Wear Strip is designed for applications where standard off-the-shelf wear resistant plastics fall short in performance. It can eliminate metal-to-metal wear and fretting damage on surfaces exposed to excessive rubbing or scuffing. Use the material where impact resistance is required, under edge loading, in heavy abrasion applications, and where gross amounts of contaminants can be expected.

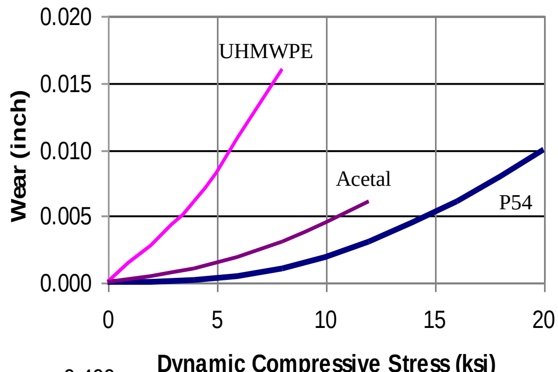
Dimensional Constraints:
Our standard processes accommodate the manufacture of P54 Wear Strip in flat sheets up to 12" x 48". The material is offered in standard grades as follows:

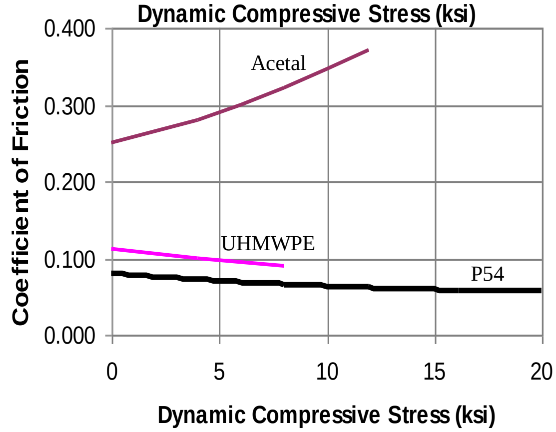
P54 Wear Strip Grade	Thickness, inches (mm)
Light Duty	.020 (.5)
Medium Duty	.032 (.8)
Heavy Duty	.060 (1.5)
Plate Stock	.120 (3.0)

Physical Properties:

Operating Temperature:	-65°F to 250°F (-54°C to 120°C)
Density:	.0466 lb/in³ (1.29 g/cc)
Hardness:	80 Shore D
Maximum Static Bearing Load:	50,000 psi (345 MPa)
Compressive Modulus:	150,000 psi (1,034 MPa)
Maximum Dynamic Bearing Load:	20,000 psi (138 MPa)

Wear Properties:
A smooth stainless steel button, 1/2" diameter, was rubbed back and forth over a .200" long path against a sample of P54 Wear Strip. Travel speed was 8"/min for 180,000 cycles. Wear and friction were measured at various loads. Test values for UHMWPE and unfilled acetal are shown for comparison.





Chemical Resistance:
P54 Wear Strip is not affected by the following chemicals: Phosphate Ester Hydraulic Fluid (Skydrol), MIL-T-5624 Turbine Fuel Grade JP-4, MIL-L-7808 Lubricating Oil, MIL-H-5606 Hydraulic Oil, MIL-A-8243 Anti-Icing Fluid, MIL-H-83282 Hydraulic Fluid, Fresh Water, Salt Water.

Bonding Procedures:
P54 Wear Strip comes with a removable woven nylon peel-ply on one surface to protect the bonding surface from dirt and debris. With the peel-ply removed and the back surface exposed, the P54 Wear Strip is prepared for bonding onto a suitable surface. A room-temperature curing structural epoxy adhesive is recommended for bonding. The following adhesives show good compatibility with the chemicals listed above: Hysol EA9460, EA9309, EA9394, and EA9396 (Loctite), Scotchweld 460 (3M Co.), Araldite 2011 (Vantico). Follow the manufacturer's suggested procedures for maximum adhesion to the mating surface.

Product Qualification:
P54 wear strip completely conforms with the requirements for self-lubricating wear strip materials in material specification DMS 2496.

KAron® V Wear Strip
Product Data Sheet

Description:
Kamatics KAron® V Wear Strip consists of standard KAron Grade V self-lubricating bearing material applied onto a thin fiberglass substrate. It is designed to be bonded onto surfaces which are subjected to light to medium duty rubbing pressure, or as a fretting resistant barrier.

Physical Properties:(1)

Coefficient of friction:	.04 - .08
Compressive strength:	30,000 psi (207 MPa)
Max dynamic load:	10,000 psi (69 MPa)
Max operating temp.:	250°F (120°C)
Wear rate:	$.5\times10^{-6}$ inch/ft of travel (41.6×10^{-6} mm/meter)
Hardness:	85 - 90 Rockwell M

Available Sizes:
Standard KAron V Wear Strip material is available in cut sheets of 12" x 48" (305 x 1219 mm), 3/4" and 1" wide strips, washers of various sizes, and custom die cut shapes. The material is available in two grades:

KAron V Wear Strip Grade	*Product Description*	*Nominal Thickness*
100	Light Duty Wear Strip	.018" (.46 mm)
200	Medium Duty Wear Strip	.036" (.91 mm)

Standard Part Numbering System:
For standard cut strip dimension parts, Kamatics uses the following part numbering system:

English dimensions: ***KWSxxx[T] - yyy - zzz***
xxx = Wear strip grade
yyy = Part width in 1/8" increments up to 12", i.e. 024 = 3" wide
zzz = Part length in 1/4" increments up to 48", i.e. 096 = 24" long
T option = 3/8" Pull tab option (for easy removal of peel ply backing)
Examples: KWS100T-016-192 = Light Duty Wear Strip, 2" x 48", with pull tab
KWS200-008-144 = Medium Duty Wear Strip, 1" x 36", no pull tab

Metric dimensions: ***KWSMxxx[T] - yyy - zzz***
xxx = Wear strip grade
yyy = Part width in 5mm increments up to 300mm, i.e. 020 = 100m wide
zzz = Part length in 10mm increments up to 1200mm, i.e. 050 = 500mm long
T option = 9.5mm pull tab option (for easy removal of peel ply backing)
Examples: KWSM200-007-095 = Medium Duty Wear Strip, 35mm x 950mm, no pull tab
KWSM100T-015-050 = Light Duty Wear Strip, 75mm x 500mm, with pull tab

Bonding Procedure:
KAron V Wear Strip comes with a woven nylon peel-ply on the back of the fiberglass to protect the bonding surface from dirt and debris. When the pull tab (T) option is called out in the part number, a 3/8" (9.5mm) long break away tab will be provided for easy removal of the peel ply backing. With the peel-ply removed and the back surface exposed, the KAron V Wear Strip is prepared for bonding onto a suitable surface. A room-temperature curing structural epoxy adhesive (2) is recommended for bonding KAron V Wear Strip material.

Notes:
1. Above reported values based on wear strip only. Physical properties in service will be largely dependent upon the adhesive bond integrity, the substrate material, and surface preparation of the substrate.
2. Suggested structural adhesives: Hysol EA9460, Hysol EA9309, Hysol EA9394 (Loctite), Scotchweld 460 (3M Co.), Araldite 2011 (Vantico).

Ultra-Light Duty ST Wear Strip

Description:
Kamatics-Ultra Light Duty ST Wear Strip is a low friction wear resistant material comprised of PTFE and other synthetic fibers with a thermoset resin designed to prevent fretting or wear damage on sliding or rubbing surfaces. The unique thin cross section of .011" (.28mm) makes Ultra-Light Duty Wear Strip ideal for aerospace surface applications that require an extremely low profile or high flexibility.

Ultra-Light Duty Wear Strip is available in cut sheets of maximum size 12" x 24" (305mm x 609mm). The material can also be cut into narrow strips, and custom cut shapes.

Physical Properties:

Thickness (without protective backing):	.011 inch ± .003 (.28 mm ± .076)
Compressive Strength:	20,000 psi (138 MPa)
Operating Temperature Range:	-65°F to 250°F (-54°C to 120°C)
Fluid Compatibility:	not affected by aerospace grade hydraulic fluid, hydraulic oil, de-icing fluid, jet fuel, water, and seawater

Dynamic Wear Properties:

Maximum Dynamic Load:	10,000 psi (69 MPa)
Coefficient of Friction:	.04 - .10 depending upon load, speed, temperature, and mating surface condition

Recommended Mating Surface Conditions:

Surface finish:	16 rms (0.4 µm) or better
Hardness:	30 HRC or better

Bonding Procedure:
Kamatics Ultra-Light Duty ST Wear Strip is applied by adhesive bonding onto a suitable substrate. It comes with a removable protective film applied to the bonding surface of the material. The running surface of the ULDST has a dark brown color, while the bonding surface has a lighter brown/olive green color (when the protective backing is removed). The mating surface should be roughened to a finish of greater than 63 rms (1.6 µm), or as recommended by the selected adhesive's manufacturer. Both surfaces to be bonded should be cleaned with an appropriate solvent (e.g. isopropyl alcohol) immediately prior to bonding.

Standard room-temperature curing structural epoxy adhesives are recommended for bonding Ultra Light Duty Wear Strip material, such as Hysol EA9309, Hysol EA9396 (Henkel Loctite Aerospace), Hysol EA9460 (Henkel Loctite Industrial), Scotchweld 460 (3M Co.), and Araldite 2011 (Huntsman).

Wear Strip
Selection Guide

Kamatics offers multiple types of Wear Strips with each providing unique characteristics to prevent metal-to-metal wear and fretting damage from sliding or rubbing surfaces. Kamatics Wear Strips are designed to be bonded onto surfaces as a protective barrier, and are available in standard sizes or custom cut profiles.

DESCRIPTION:

KAron V Wear Strip consists of standard KAron Grade V self-lubricating bearing material applied on to a thin fiberglass substrate. The KAron V bearing material provides a low sliding friction for wear resistance. KAron V Wear Strip comes with a removable woven nylon peel-ply on the back of the fiberglass to protect the bonding surface from dirt and debris.

P54 Wear Strip is a thin sheet self-lubricating bearing material comprised of a resilient thermoset resin matrix with synthetic fibers in a laminate construction for strength and durability. P54 Wear Strip comes with a removable woven nylon peel-ply on one surface to protect the bonding surface from dirt and debris.

APPLICATION INFORMATION:

KAron V Wear Strip is designed for surfaces that are subjected to light to medium duty rubbing pressure, or as a fretting resistant barrier. The mating sliding material should be smooth, hard, and a corrosion resistant surface. For optimal KAron V liner performance, the sliding component should have a minimum surface roughness of 16 RMS (0.4 μm), and be in full contact with the KAron V Wear Strip to avoid line or point loads.

P54 Wear Strip is designed for applications where standard off-the-shelf wear resistant plastics fall short in performance. P54 Wear Strip can be used where impact resistance is required, under edge loading, in heavy abrasion applications, and where gross amounts of contaminants can be expected. P54 Wear Strip can operate against rough surfaces and against soft materials such as aluminum or composites.

Kamatics Wear Strips are flexible and can conform to the contour of a mounting surface – please consult Kamatics Engineering for application design recommendations.

PHYSICAL PROPERTIES[1]:

	KAron V Wear Strip	P54 Wear Strip
Coefficient of Friction	0.04 – 0.08	0.06 – 0.08
Max Static Load	30,000 psi (207 MPa)	50,000 psi (345 MPa)
Max Dynamic Load	10,000 psi (69 MPa)	20,000 psi (138 MPa)
Operating Temperature	-100°F to 250°F (-73°C to 120°C)	-65°F to 250°F (-54°C to 120°C)

Table 1

[1] Above reported values based on wear strip only. Physical properties in service will be largely dependent upon operating conditions, the mating surface, the adhesive bond integrity, the substrate material, and surface preparation of the substrate.

FLUID COMPATIBILITY:

Kamatics Wear Strips are not affected by the following chemicals: Phosphate Ester Hydraulic Fluid (Skydrol), MIL-T-5624 Turbine Fuel Grade JP-4, MIL-PRF-7808 Lubricating Oil, MIL-PRF-5606 Hydraulic Oil, MIL-A-8243 Anti-Icing Fluid, MIL-H-83282 Hydraulic Fluid, Fresh Water, Salt Water.

ENVIRONMENTAL TESTING:

Kamatics KAron V and P54 bearing materials performed very well in independent laboratory testing. The methods used for the testing were MIL-STD-810F Environmental Engineering Considerations and Telecordia General Requirements. When subjected to tests for High and Low Temperatures, Solar Radiation, Blowing Rain, Fungus, Humidity, Salt Fog, Blowing Dust, Functional Shock, and Ozone Resistance, the Kamatics bearing material test samples showed no signs of damage or degradation.

ORDERING INFORMATION:

Standard Kamatics Wear Strip materials are available in flat sheets up to 12" x 48" (305 x 1219 mm). Kamatics Wear Strips are also available in cut strips as narrow as 1/2" wide up to the maximum sizes. For washers of various sizes, and custom cut shapes and profiles, contact Kamatics for ordering information. Wear Strip bearing materials are available in the following grades:

Wear Strip Type	Material Letter	Wear Strip Grade	Product Description	Nominal Thickness, inches (mm)	Temperature Capability
KAron V Wear Strip	S	100	Light Duty	0.018 (0.46)	N/A
		200	Medium Duty	0.036 (0.91)	N/A
P54 Wear Strip	P	020	Light Duty	0.020 (0.5)	N/A
		032	Medium Duty	0.032 (0.8)	N/A
		060	Heavy Duty	0.060 (1.5)	N/A
		120	Plate Stock	0.120 (3.0)	N/A

Table 2

STANDARD PART NUMBERING SYSTEM:

For standard cut strip dimension parts, Kamatics uses the following part numbering system:

KW	__	__	__ __ __	__	–	______	–	______	__ __
Kamatics Wear Strip	Material Letter	Units of Measure	Wear Strip Grade	Optional Pull Tab		Width		Length	Temperature Capability

Material Letter = ***S*** for KAron V Wear Strip
P for P54 Wear Strip
Unit of Measure = (***BLANK***) for English units
M for Metric units
Wear Strip Grade = See Table 2 above
Optional Pull Tab = (***BLANK***) for no Pull Tab
T for optional Pull Tab – KAron V Wear Strip ONLY – 3/8” Pull Tab for easy removal of peel-ply backing
Width = English units: width in 1/8" increments up to 12", example 024 = 3" wide
Metric units: width in 5mm increments up to 300mm, example 020 = 100mm wide
Length = English units: length in 1/4" increments up to 48", example 096 = 24" long
Metric units: length in 10mm increments up to 1200mm, example 050 = 500mm long
Temperature Capability = ***(BLANK)*** for Karon V Wear Strip and P54 Wear Strip

Part Number Examples:
KWS100T-016-192 = KAron V Light Duty Wear Strip, 2” x 48”, with pull tab
KWSM200-007-095 = KAron V Medium Duty Wear Strip, 35mm x 950mm, no pull tab
KWP060-096-192 = P54 Heavy Duty Wear Strip, 12” x 48”

BONDING PROCEDURE:

KAron V Wear Strip comes with a removable woven nylon peel-ply on the back of the fiberglass to protect the bonding surface from dirt and debris. When the pull tab (T) option is called out in the part number, a 3/8" (9.5mm) long breakaway tab will be provided for easy removal of the peel ply backing. With the peel-ply removed and the back surface exposed, the KAron V Wear Strip is prepared and ready for bonding on to a suitable surface.

P54 Wear Strip comes with a removable woven nylon peel-ply on one surface to protect the bonding surface from dirt and debris. With the peel-ply removed and the back surface exposed, the P54 Wear Strip is prepared and ready for bonding on to a suitable surface.

Standard room-temperature curing structural epoxy adhesives are recommended for bonding Kamatics Wear Strip material, such as Hysol EA9309 (Henkel Loctite Aerospace), Hysol EA9396 (Henkel Loctite Aerospace), Hysol EA9460 (Henkel Loctite Industrial), Scotchweld 460 (3M Co.), and Araldite 2011 (Huntsman). Follow the manufacturer's suggested procedures for maximum adhesion to the mating surface. The mating adherent surface should have or be roughened to a finish of greater than 63 RMS (1.6 μm), and be cleaned with an appropriate solvent (e.g. isopropyl alcohol) immediately prior to bonding.

WEAR STRIP PRODUCTS WITH “SELF-STICK” ADHESIVE:

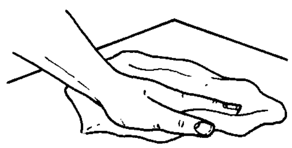
Kamatics manufactures several wear strip products with an integral acrylic pressure sensitive “self-stick” adhesive for ease of assembly. This form of adhesive is suitable for non-contaminated applications below 150°F (66°C). Kamatics wear strips with self-stick adhesive are custom products – contact Kamatics for product availability.

SELF-STICK BONDING PROCEDURE:

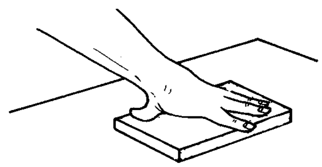
The following instructions are recommended for optimum self-stick adhesive strength.

Surface preparation

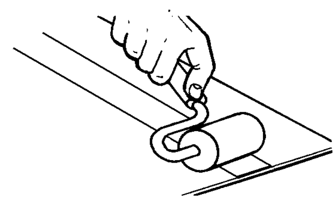
The self-stick adhesive will adhere well to most clean, dry surfaces. Typical surface cleaning solvents are a 50/50 isopropyl alcohol (rubbing alcohol)/water mixture. Scrubbing the surfaces with a solvent saturated mild abrasive pad and then wiping the surface with a clean cloth to remove the solvent and contaminants provides good results. Follow solvent manufacturer's precautionary warnings and suggested handling procedures when using solvents.



Step 1: Solvent wipe



Step 2: Clean dry



Step 3: Apply adhesive with pressure

Bonding Pressure

Bond strength is dependent upon the amount of adhesive-to-surface contact developed. Firm application pressure develops better adhesive contact and thus improves bond strength. The most common technique is to apply the exposed self-stick adhesive backing onto the cleaned surface, then apply very firm pressure to the entire bond line. This can be accomplished by rolling a soft hand-held plastic roller against the wear strip surface, or by clamping a solid face sheet against the wear strip surface.

Application Temperature

Ideal adhesive application temperature range is 70°F to 100°F (21°C to 38°C). Initial application to surfaces at temperatures below 50°F (10°C) is not recommended because the adhesive becomes too firm to adhere readily. However, once properly applied, low temperature holding is generally satisfactory.

Dwell Time

After application, the bond strength increases and approaches the ultimate bond strength after 72 hours at 70°F (21°C). In some cases bond strength can be increased and ultimate bond strength can be achieved more quickly by exposure of the bond to elevated temperatures; i.e. 150° F (66° C) for 1 hour. This provides quicker and more thorough adhesive wet out onto the substrate.

Kamatics KAron Wear Strip
Bonding Procedure for General
Purpose Installations, <160°F (<70 °C)

Introduction
Kamatics KAron coated Wear Strips offer the capability to coat and protect moving parts by field application of self-lubricating bearing materials. When attaching the Kamatics Wear Strip, care should be taken in the field bonding procedure to assure adequate adhesion of the Wear Strip to the substrate to be protected. The Kamatics Engineering Technical Note provides a procedure for general purpose bonding of Kamatics Wear Strips where operating temperature will not exceed 160°F (70°C) and operating loads are low.

General

- A reliable bonding procedure requires care in the following:
- Adhesive selection and control
- Substrate cleaning
- Substrate preparation
- Bond line thickness control
- Curing procedure.

This Engineering Technical Note addresses each of the above elements to provide the user with a step-by-step procedure for general purpose bonding of Kamatics Wear Strips .

Adhesive Selection and Control
For bonding Wear Strips, Kamatics recommends the use of Hysol Epoxy Adhesive EA 9309.3 NA, or equivalent. Important characteristics of the adhesive are:

- Adequate working time for the particular installation
- 160°F (70°C) operating temperature
- Integral bond line control (suspended glass beads or fabric carriers)

The final bond quality can be adversely affected by improper handling and storage of the adhesive. Therefore, all adhesives must be stored and handled strictly in accordance with the manufacturer's instructions and must not be used beyond their published shelf life.

Substrate Cleaning
The substrate should be thoroughly cleaned to remove all traces of dirt, oils, and other contaminants.
For substrates which are heavily contaminated, the surfaces to be bonded should first be cleaned using a detergent cleaner and thoroughly rinsed with hot water.

Cleaning of the surface to be coated should be by washing or wiping with trichloroethane, acetone, or alcohol.

No cleaning of the Kamatics Wear Strip is required. The surface of the Wear Strip to be bonded is protected by an integral "peel ply" applied to the surface to be bonded. Removal of this "peel ply" exposes a surface which is clean, roughened, and ready for bonding.

All parts, following cleaning, should be handled only by personnel using clean, lint free gloves. Contamination of cleaned surfaces must be avoided, and any such contamination requires re-cleaning of the parts.

Substrate Preparation
In order to achieve a reliable bond between the Kamatics Wear Strip and the substrate, both surfaces should be mechanically roughened to provide a surface most receptive to adhesion.

As mentioned previously, the "peel ply" applied to the back of the Wear Strip, when removed exposes a surfaces which is already clean, properly roughened, and ready for bonding.

The substrate should be mechanically roughened using an alumina grit paper (80-200 grit is adequate) or using alumina grit in a grit blast operation, to remove all surface deposits. Re-clean the surfaces after roughening. Bond as soon as possible.

Proper Bond Line Thickness Control
In order to achieve the highest possible bond strength, the bond line thickness must be controlled. The best method for controlling the bond line thickness is to use an adhesive with an integral method of bond line control.

Adhesive EA 9309.3 NA is a liquid which incorporates 0.005" diameter glass beads for bond line control. The liquid is applied to one or both surfaces to be bonded, and the surfaces are pressed together until the excess adhesive is squeezed out from between the surfaces. The glass beads prevent the surfaces from being pressed closer together than 0.005" (0.125 mm), providing the optimum bond line thickness.

Proper Curing Procedure
The final bond quality can be adversely affected by improper curing of the adhesive. Therefore, all curing operations must be performed strictly in accordance with the manufacturer's instructions. EA 9309.3 NA provides optimum strength when cured at 70°-80°F (20°-25°C) for 5 to 7 days. The bond will develop sufficient strength for handling after 6 hours at room temperature, and fixturing to hold the part pressed together should be used until handling strength is developed. Time to develop handling strength can be greatly reduced by application of heat (do not exceed 250°F for this purpose).

Kamatics Wear Strip
Bonding Procedure Summary

Adhesive:
- Hysol EA9309.3 NA or equivalent.

Cleaning:
- Clean heavily contaminated surfaces using a detergent cleaner and thoroughly rinse with hot water.
- Clean the surface by washing in trichloroethane, acetone, or alcohol.

Surface Preparation (Substrate):
Mechanically roughen using an alumina grit paper (80-200 grit is adequate) or using alumina grit in a grit blast operation, to remove all surface deposits. Re-clean after roughening.
- Handle only with clean, lint free gloves.
- Apply adhesive as soon as possible.

Surface Preparation (Wear Strip):
Remove the "peel ply" from the back of the wear strip (a sharp object such as a knife is useful for initiating separation of the "peel ply" from the Wear Strip).
- Handle only with clean, lint free gloves.
- Apply adhesive as soon as possible.

Bond Line Control:
Apply a thin coat of adhesive to both the surface and to the back surface of the Wear Strip (or, if using a film adhesive, apply the pre-cut adhesive film to the back of the Wear Strip).

Press the Wear Strip against the substrate until excess adhesive no longer is squeezed from between the parts. (Wiping the excess adhesive from the parts at this point will reduce the effort required for cleanup of the parts.)

Bond Curing:
Keeping the parts pressed together, cure the bond to handling strength at room temperature 70°-80°F (20°-25°C) for 6 hours. Fully cure the bond at room temperature for 5 to 7 days.
- Clean up excess adhesive as required.

APPENDIX E

Photo showing the scope and size-range of Kamatics capabilities. Bearings shown are made from stainless steel, aluminum, bronze, titanium and composites. KAflex driveshaft couplings made from stainless, titanium, and maraging steels.

Photo showing KAron lined sleeve and journal bearings for use in various landing gear applications.

Photo showing complex configurations to which the KAron liner is applied.

Photo showing various sizes of spherical bearings produced by Kamatics.

Pictured above are typical KAron lined track rollers, cam followers, and track sliders. Bearings shown are used on large commercial, business and regional aircraft track, slat and door mechanisms among other places.

Composite bearings; filament wound, braided and laminated construction all with a KAron liner applied are depicted above. Sleeves, thrust washers, flanged journals, guide strips and bars are shown. Glass, carbon, polyester and other fibers are combined with various resins including epoxy and polyester.

Notes