Ultimate Surface Performance

Innovative Solutions for Corrosion, Wear and Friction Reduction

**Liquid Nitriding
Arcor/Melonite, QPQ Treatments**

**Innovative PVD Technology
& PVD Coatings**

**High-Performance, Engineered
Sleeve Bearings & Bushings**

hefusa.com

HEF Overview

The HEF Group, based in France, has been a global leader in the science of tribology (wear & friction) for more than 50 years. Established as a research and development company, HEF subsequently applied its knowledge and experience to develop surface engineering solutions for improving the performance of industrial and automotive components.

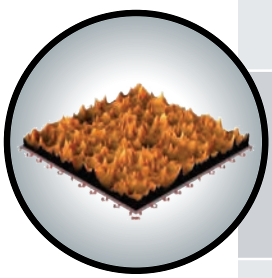
Today, HEF is active in more than 20 countries throughout Europe, Asia, and the Americas, engaged in providing **Controlled Liquid Ionic Nitriding (CLIN)** services & chemicals; **PVD**-based coating services; **tribology testing** services; and supplying **engineered bushings** for demanding industrial applications.

HEF USA sells and markets (a) chemicals for Controlled Liquid Ionic Nitriding (Salt Bath Nitriding) – a family of proprietary nitro-carburizing processes commercialized under the trade names of ARCOR®, MELONITE®/QPQ and (b) engineered bushings for industrial applications.

TECHIQUES SURFACES USA (TS USA) is the commercial processing unit of HEF – operating independent jobbing facilities or JVs with licensees and partners who offer HEF's portfolio of CERTESS® PVD coatings & CLIN treatment services to industrial customers.

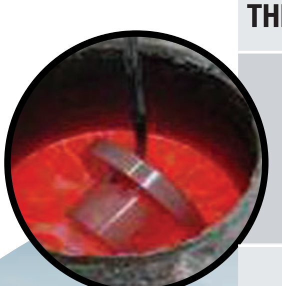
3 Competencies

TRIBOLOGY



- Wear analysis and friction testing
- Failure mode analysis for mechanical components

THERMOCHEMISTRY & DIFFUSION LAYERS



- Thermal treatment in molten salt
- Thermochemical treatment in molten salt: liquid nitriding

THIN FILM PVD COATINGS

- PVD & PECVD wear – resistant, hard coatings
- PVD coatings for electro-magnetic shielding, IR filtering, etc.

3 Business Models

JOBBING

- Thermochemical treatment
- PVD/PECVD
- SULF BT®, DOT®, TEGLISS®, etc.

TECHNOLOGY TRANSFER

- Licensing
- Engineering support
- Equipment
- Consumables

FRICTION COMPONENTS

- Bushings & sleeve bearings
- Washers
- Spherical bearings
- Shafts
- Slides

Tribology Testing

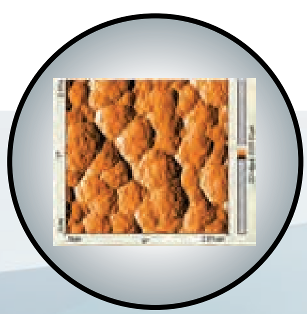
Tribology – the science and technology of interacting surfaces in relative motion – is critical to understanding and optimizing surface performance and service life. Expertise in tribology produces critical information regarding wear/contact modes and failure mechanisms of mechanical components, resulting in solutions that improve performance and/or reduce costs.

HEF has extensive resources for comprehensive study of wear and friction control/management:

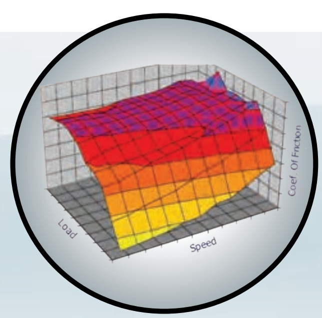
- Database of over 80,000 friction tests
- Special environment testing: cryogenic; temperatures up to 1200°C; oil, grease, fuel and water lubrication
- Microscopy: Optical, Scanning electron with EDS analysis and Atomic Force
- Corrosion testing
- 3D surface topography & 2D/3D profilometry
- More than 40 types of test beds for accelerated wear simulation and characterization of wear behavior
- Wetting, measurement of surface energy, cleanliness measurement using Coronasurf™ technology
- Micro & Nano hardness measurements

HEF's Institute of Research In Surface Engineering (IREIS) performs contract R&D and tribology studies for industry & academic institutions worldwide. Our innovative solutions and expertise include the following:

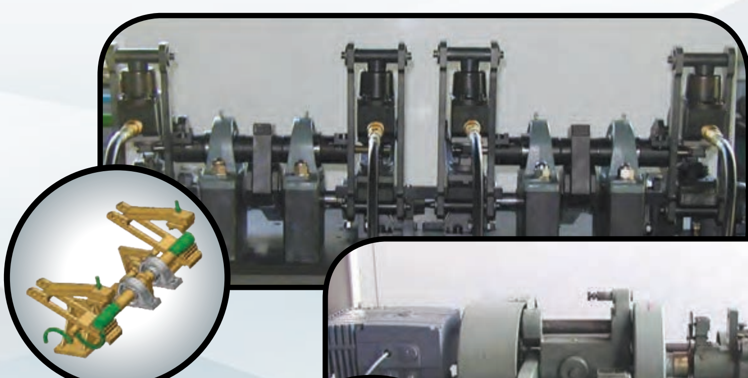
- Assist in the design and development of new products and improvement of existing processes or products (performance or service life enhancement, improvement of system productivity)
- Optimization of materials, products, lubrication and maintenance
- Solutions to mechanical problems such as seizure, wear or excessive noise
- Tribology expertise in areas such as:
  - Tribology of plain bearings (boundary lubrication, high load and/or low speed)
  - Friction in poorly lubricating mediums (water, gas)
  - Dry or boundary lubrication, including materials for dry sliding (polymers, organic films)
  - High temperature friction.
  - Tribology & mechanical behavior characterization of thin-film coatings

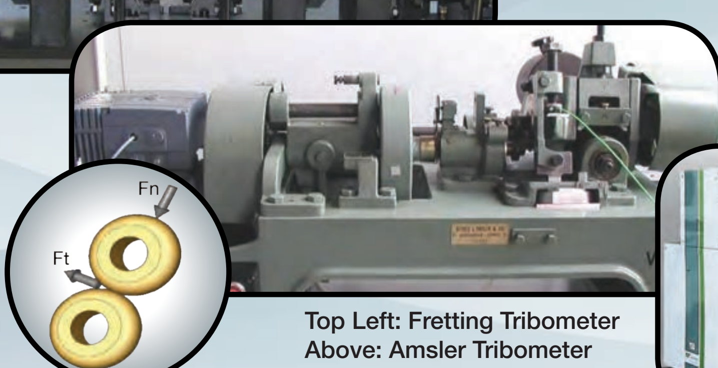


Above: Surface Characterization



Above: CoF under different operating conditions





Top Left: Fretting Tribometer
Above: Amsler Tribometer
Right: Oscillation Simulator

Controlled Liquid Ionic Nitriding (CLIN) Overview

CLIN (Liquid Nitriding) is a subcritical surface enhancement process with one of the longest track record of success of any case hardening technology. It is widely used to enhance the wear and corrosion resistance of low alloy steels and stainless steels.

In a liquid nitriding bath which is maintained between 500 - 630°C (930 - 1165°F), nitrogen-bearing salts produce a controlled and highly uniform release of nitrogen at the interface of the workpiece. Nitrogen diffuses into, and chemically combines with, nitride-forming elements in the metal, producing, through a catalytic reaction, a tough, ductile compound layer with exceptional engineering and wear properties.

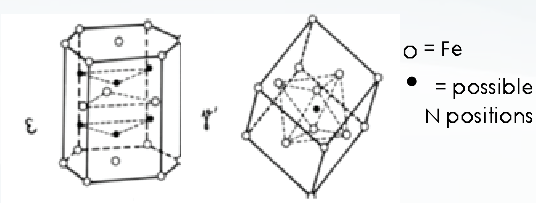
Melonite® and the Arcor® Series are the world's premier liquid nitriding processes. Melonite & Arcor processes comply with industry standards SAE/AMS 2753 and are widely specified for critical components. For many applications, they are a superior alternative to hard chrome plating.

This compound layer has wear properties that are 200% to 1000% greater than the original material, and greatly enhanced resistance to corrosion, galling and scuffing. Below the compound zone is another distinctive region, the diffusion zone. This results from the progressive diffusion of nitrogen and the formation of a solid solution of nitrogen in the base material. The diffusion zone contributes a critical fourth benefit of salt bath nitriding: substantial enhancement of fatigue strength, typically 20% to 100%.

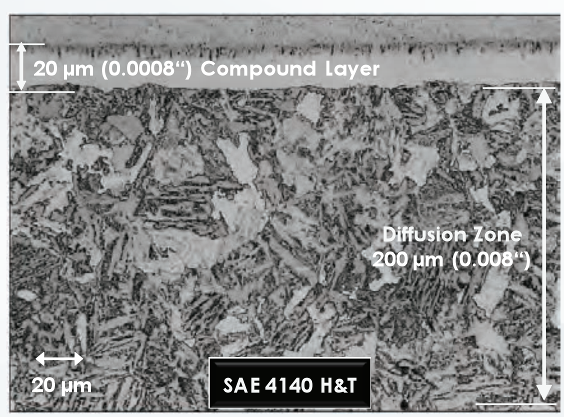
The following are some of the benefits that can be realized after liquid nitriding treatments of components:

- Superior wear resistance
- Excellent friction properties
- Good scuffing/seizure protection (adhesive wear) thanks to ceramic characteristics of the surface
- Excellent corrosion protection
- Good surface fatigue resistance
- Decorative black surface
- No deformation or distortion of the part; treatment done on finished parts
- Environmentally sound

The **Compound Layer (CL)** is essentially ε (epsilon) iron nitride + special nitrides (in case of alloyed steels) + some iron oxides.



Diffusion Zone: The area below the compound layer where nitrogen diffuses into the iron lattice to form a solid solution.



CLIN Process

Melonite® Processes

Melonite, and its synonymous trade-name, Tufftride® (or Tenifer®), is a relatively straight-foward, flexible Liquid Nitriding process to operate and maintain, and delivers exceptionally uniform case hardening. The Melonite process begins with the placement of parts in a re-circulating air pre-heat furnace, followed by immersion for anywhere between 60-240 minutes in a molten nitrogen-rich salt solution contained in an aerated furnace. After nitriding, parts are treated in an oxidizing bath, water-cooled and rinsed. An alternative series of post-nitriding steps involves a Quench-Polish-Quench (QPQ) sequence after Liquid Nitriding. For many applications, this finishing process provides a surface condition that protects against corrosion and wear better than hard chrome or nickel plating.

Arcor® Processes

The Arcor family of processes represents the latest in Liquid Nitriding technology. **Arcor V has become the most widely used process variant, due to its excellent combination of wear, friction and corrosion protection for a diverse range of low & medium carbon steels; high-nickel, high-chromium steels; and cast irons**. Arcor V processing begins with immersion in a liquid media between 500-590°C , to produce a 10-25 micron surface layer of epsilon iron nitride above a nitrogen diffusion layer; an oxidizing bath to enhance corrosion performance; a rinsing step; and finally an optional impregnation, which penetrates the surface micro-porosity in the iron oxy-nitride, further enhancing corrosion protection.

Arcor V delivers both hardness and ductility. Its ductile compound layer provides outstanding resistance to wear and corrosion. When used with HEF's proprietary post-nitriding impregnation treatment, Arcor V salt-spray corrosion performance on certain components can be up to 1000 hours, per ASTM B117.

Parts treated with Arcor V effectively resist seizure. The micro-layer inhibits the formation of frictional welding points and assists the running-in of components. The hard, yet ductile surface layers make Arcor treated parts compatible with mating surfaces without surface cracking or exfoliation. Finally, the Arcor V process produces substantial improvements in fatigue resistance. Arcor V has also proved its ability to improve compound layer quality – particularly for cast irons.

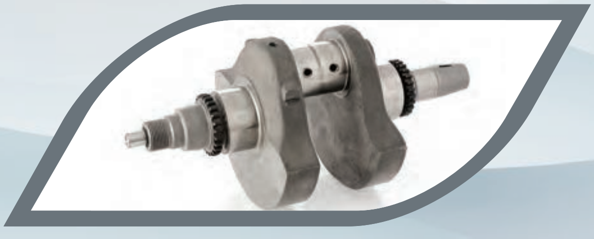
Arcor N is distinctive in that it is an austenitic, rather than a ferritic nitrocarburizing treatment, with a process temperature of 630°C. Arcor N was engineered for improved ductility and better economy due to shorter process cycles.

HEF has developed additional Arcor treatments for customized applications – such as lower process temperatures; lower surface roughness; improved corrosion protection etc.

CLIN Applications

Application	Advantages of CLIN
Gear box selector shafts	• Layer free of cracks • Corrosion resistance • Cost reduction
Cam rollers for common rail injection pumps	• Reproducibility • Wear resistance • Running behavior • Longer service life
Suspension & steering ball studs	• Superior corrosion resistance: 240 hrs on polished areas • Improved durability
Engine valves	• Superior scuffing resistance • Greater uniformity • More economical
Brake rotor	• Superior corrosion resistance • Minimizes brake pulsation issues
Pistons on brake disc system	• 16x times superior corrosion resistance
Actuator RAM assembly: parking brake pneumatic cylinder	• Cost reduction: low carbon steel + liquid nitriding • Improved corrosion & wear resistance

Application	Advantages of CLIN
Latch plates	• Higher corrosion resistance • Material strengthening • Weight reduction • Cost reduction due to material savings
Differential assembly	• Price reduction of about 30% • No superficial interface between substrate & crack-free nitride layer • Excellent friction properties • No cracking or flaking due to superficial fatigue
Hydraulic cylinders	• Superior corrosion resistance • Improved wear resistance • Lower friction forces • Higher environmental favorability • No peeling when cylinders flex
Pump components	• Superior corrosion resistance • Good wear and seizure resistance with high speed operation
Shafts & pins	• More ductile than results obtained from conventional surface treatments; surface cracks limited under flexion • No peeling nor flaking during assembly or running
Handguns & rifles	• More durable and scuff-resistant; lower friction on sliding parts • Much better corrosion/rust resistance



PVD Coatings Overview

While liquid nitriding is a surface modification technology, physical vapor deposition (PVD) involves the deposition of thin (2-10 microns; 0.0001”–0.0004”) films on the surface of tools and components. The PVD coating process can be divided into three stages:

- **Evaporation** – Removal of material from the target, source or cathode.
- **Transportation** – Travel of evaporated material from the source to the substrate.
- **Condensation** – Nucleation and growth of the coating on the substrate surface.

Material is usually removed from the target surface either by sputtering or by an arc-discharge. The transportation step is through a plasma medium. Plasma is a collection of charged particles, whose constituents can be influenced by magnetic fields and tend to travel in straight lines or “line of sight” from source to substrate. Different characteristics are imparted to the plasma depending upon the technique used to generate it. PVD coatings are formed when plasma constituents and reactive gases combine on the substrate surface. Besides its specific chemical constituents and the architecture of the sub-layers, the properties of a PVD coating depend upon: ion energy; the degree of ionization of the metal ions; and mobility of the atoms condensing on the substrate surface.

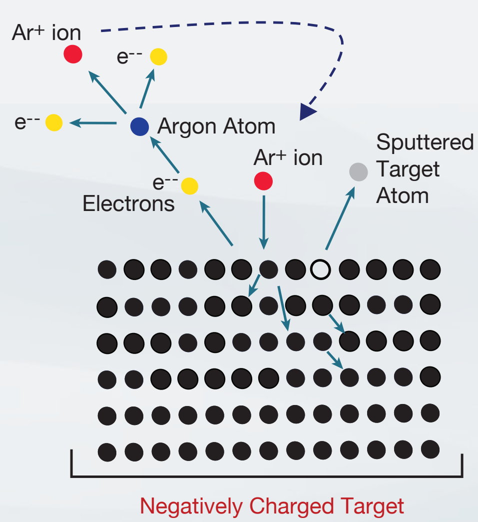
There is a broad range of available PVD technologies – including conventional **arc deposition and magnetron sputtering**, coupled with technology enhancements that yield high deposition rates and thin films with high adhesion and diverse microstructures. HEF PVD coatings are deposited using three different technologies:

PEMS: *Plasma Enhanced Magnetron Sputtering*. HEF patented PEMS is a magnetron sputtering process enhanced by an auxiliary plasma source. This triode system allows independent control of material flux, ion energy and substrate bias. PEMS can provide a multitude of high performance coatings with application customized hardness, density and toughness.

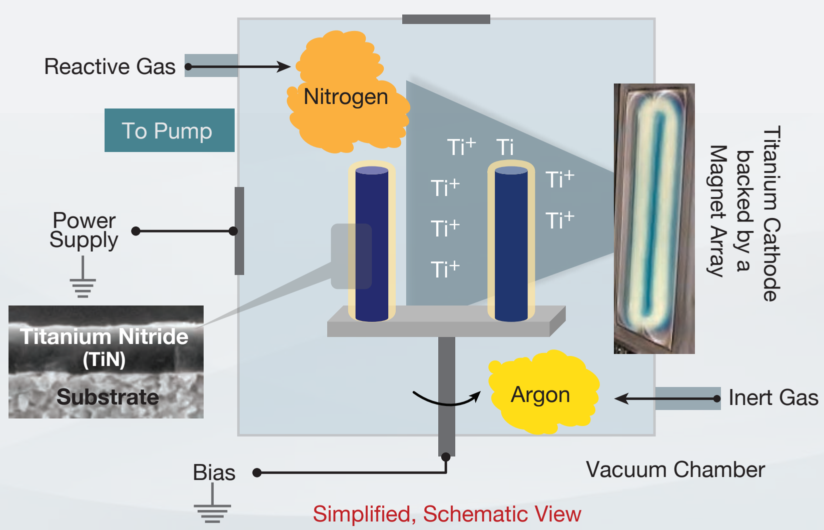
CAM: *Coating Assisted by Microwaves*. CAM permits the deposition of hard and ultra-low friction coatings at a very low temperature. Another major advantage is the ability to coat at low pressure, allowing more efficient use of the coating chamber and improved productivity.

M-ARC: *Modified ARC*. This high throughput plasma-arc method was developed by HEF partner, Northeast Coating Technologies (NCT), and dramatically reduces droplets normally associated with arc-deposited coatings. These coatings are a cost-effective solution for a wide range of carbon-free PVD coatings.

Sputtering



Magnetron Sputtering



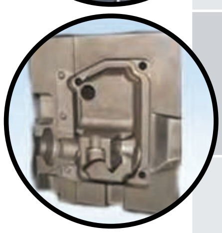
Sputtering produces metal vapor plasma from a solid cathode by bombarding the surface with energetic gas ions (i.e. Argon). Reactive gases (i.e. nitrogen or hydrocarbon gas) combine with the metal vapor to form PVD coatings (i.e. TiN, CrN, Ti(C,N)).

PVD Applications

HEF's PVD coatings improve performance, add value, and solve critical challenges associated with friction & wear reduction. Some specific advantages of these coatings for industrial, automotive, and medical applications components are as follows:

- **High resistance** to wear, abrasion and erosion.
- **Low friction** coefficient under high and low temperature conditions, with or without humidity. This translates into lower power losses and higher efficiency.
- **Higher load carrying capacity** with fewer lubricant additions, and less erosion.
- **Material flexibility** – prudent PVD coating solutions allows manufacturers to specify less expensive base materials without compromising product performance.
- **Biocompatibility** for medical and food-contact applications.
- **Hard chromium & nickel plating replacement** for a broad range of performance (non-decorative) applications




Material	Hardness (HV)	Max. Usage Temp	Coating Thickness (microns)	Dep. Temp	Coef. of Friction (dry) against Steel	Typical Applications
CERTESS® N: Cr-N	1800	700° C	1 - 5	150° C - 350° C	0.5	• Forming tools • Plastic & rubber molds for wear and adhesion • Moderate wear mechanical & auto components
CERTESS® X: Crx-Ny	2200	700° C	1 - 5	150° C - 350° C	0.5	• Same as CERTESS® N
CERTESS® T: Ti-N	2700	500° C	2 - 6	250° C - 450° C	0.4	• Moderate wear mechanical components • General purpose cutting tools • Decorative
CERTESS® G: Zr-N	2700	500° C	2 - 6	250° C - 450° C	0.4	• Same as CERTESS® T, with better corrosion resistance
CERTESS® Ti: Ti-Al-N	3000	800° C	1 - 5	300° C - 450° C	0.3	• Mechanical components – abrasive wear resistance at high temperatures • Cutting tools for hard-to-cut materials
CERTESS® SD: Ti-B-N	4500	800° C	1 - 5	300° C - 450° C	0.3	• Aluminum die-casting
WC-C based CERTESS® coatings	1500 - 2000	350° C	2 - 4	150° C - 350° C	0.20 - 0.25	• Friction & wear reduction of automotive and industrial equipment components
DLC based CERTESS® coatings	2800 - 3200	350° C	2 - 4	150° C - 350° C	0.10 - 0.15	• Friction & wear reduction of automotive and industrial equipment components

Hardness (HV): Tungsten Carbide = 1400, Nitrided Steel = 1100, Hard Chrome = 1000, Hardened Tool Steels = 750, Carbon Steels = 500, $CuBe_2$ = 430

PVD Coatings: Automotive and Wear Components

In recent years there has been a concentrated drive to **lower automotive carbon emissions and decrease fuel consumption**. To achieve higher performance standards engine design has continued to evolve. Innovations in valve train design; gasoline turbo-charging; engine downsizing; direct injection technology etc are placing increasing mechanical and thermal stresses on many engine components. The importance of improving the durability/reliability and reducing friction between sliding and rotating surfaces of precision components used in industrial equipment such as pumps, valves, compressors, gear-boxes, etc. is also well recognized.

In order to meet the diverse operating conditions encountered by engineered components used for automotive and other generic industrial applications, HEF has developed a family of diamond-like-carbon (DLC) coatings. These coatings usually include several layers of different materials such as Cr, CrN, W, WC-C, Si with a top layer of amorphous carbon, with or without hydrogen.

The properties of DLC coatings in terms of **hardness; coefficient of friction; roughness; adhesion level; load carrying capacity; resistance to humidity influenced degradation; fatigue tolerance, etc.** can be tailored over a wide range depending upon deposition parameters, deposition technology and the combination of materials constituting the coating.

Over the past few years, HEF has developed a series of successes with niche DLC and WC-C based coatings for components such as automotive tappets, piston pins and rings, shafts, fuel-system components, etc. HEF has also demonstrated the capability to handle large volumes of automotive parts using specially designed robotics; pre and post-coat surface finishing capability and a robust quality management system, including TS 16949.

HEF also offers a range of PVD coatings for **optical property enhancement, electromagnetic shielding (PROCEM®) and the enhancement of aesthetics** (such as imparting a metallic appearance on polymers and glass).

DLC Based PVD Coatings
CERTESS® DC: **a-C:H**
CERTESS® DCi: TiN + **a-C:H**
CERTESS® DCT: TiAlN + **a-C:H**
CERTESS® DCS: TiBN + **a-C:H**
CERTESS® DCX: Cr_xN_y+ **a-C:H**
CERTESS® DCN: CrN + **a-C:H**
CERTESS® DCP: Cr + **a-C:H**
CERTESS® DDT: WC-C + **a-C:H**
CERTESS® DCY: Cr + WC-C + **a-C:H**

Properties	Range for DLC based coatings
Scratch test Lc (N)	20 - 40
HV (kg/mm^2)	2,800 - 3,200
E' (GPa)	190 - 210
Abrasion ($\mu m^3/s$)	1,000 - 2,000
Coef. of Friction (dry)	0.10 - 0.15
Boundary CoF in 5W30	0.07 - 0.11
Load carrying capacity	High
Applications	Run-in + Load Run-in + Load + Scratch

Under Layer = a variety of materials selected dependent upon: required load bearing capacity; wear mode & contact mode; adhesion and other metallurgical considerations. **Top Layer** = **a-C:H**

Engineered Bushings & Sleeve Bearings Overview

For more than 50 years, HEF has designed and developed high performance bushings, rings and joints for demanding applications in industries such as construction, mining, railroad, and agriculture. HEF bushings are recognized worldwide for their excellent **frictional and anti-seizure properties**, and their ability to **withstand high loads**. HEF bushings are also industry's choice for applications requiring **extended intervals between lubrication**. Our extensive tribology laboratories give our customers a major advantage in determining precisely what bushings will best meet stringent performance and cost requirements.

Three factors combine to give our engineered bushings exceptional serviceability for high-load/low rotational speed applications that are our specialty. Those factors are:

- **Advanced base materials**
- **Patented surface treatments**
- **Patented surface topographies & textures: cross-hatching & surface cavities**

Cross-hatching involves a network of grooves on the inner surface of the bushing. For a lubricated joint, a grease reservoir is built-up in the interconnecting channels, allowing lubrication intervals to increase by as much as 100%. Debris present in the contact zone often exhibits very high hardness, leading to premature joint wear in many industrial situations. Cross-hatching allows effective evacuation of unwanted particles and debris.

Surface cavities provide a lubricant reserve, allowing the joint to be operated maintenance-free, or with very long lubrication intervals. Grease is not evacuated and is retained at the contact points. For high sliding speeds, surface cavities allow the onset of a local hydrodynamic friction mode: contact pressure is then borne by the local grease bearings.

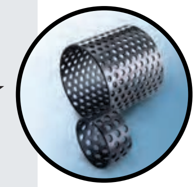
HEF offers several patented bushing designs, in a broad range of sizes, as well as carburized and ground sleeve bearings. To determine the best design for a particular application, designers should first consider the constraints of the work environment, including abrasion, loading, corrosion and maintenance requirements.

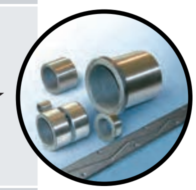
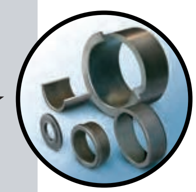
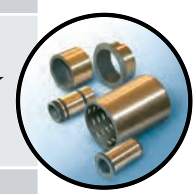
When selecting the appropriate bushing for each application, the pressure-velocity (PV) factor is particularly important. For joints operating under dry or greased conditions, the thermal energy generated by friction is proportional to the pressure (P), the sliding velocity (V) and the friction coefficient (F) between the sliding surfaces. Given a pair of materials, there is a maximum PV beyond which surfaces can no longer absorb the generated friction, leading to seizure or melting of the surfaces. Each of the HEF bushing designs has its own PV curves, which are indispensable for determining the appropriate bushing for particular applications and operating conditions.

In addition to bushings and bearings, HEF supplies a broad range of other friction components, including pins, shafts and sleeves; slides and pads, washers, rollers, screws and nuts.

Engineered Products: Bushings & Sleeve Bearings

Application	Max. Pressure (N/mm2)	Max. Sliding Speed (M/S)	Reduced Maintenance	Abrasion Resistance	Corrosion Resistance	Max. Temperature	Resistance to Shocks and Vibrations	Misalignment
PEL®-T • High load • High speed • Reduced maintenance • Suitable for high contact pressure and abrasion	100	8	★★★	★★	★★	250°C 480°F	★★	★
PEL®-BH, BH 2, BH-HG • High load • High surface hardness • Shock, pressure and abrasion-resistant	200	1.5	★★★	★★	★★	250°C 480°F	★★★	★
PEL®-PEL, HP • High load • Shock loads	100	0.5	★	★★	★★	250°C 480°F	★★★	★
FAM® • Abrasion • Shock loads • Maintenance-free • High temperature	50	0.5	★★★	★★★	★	380°C 720°F	★★★	★
COD 11® • Corrosion-resistant	60	0.2	★	★	★★★	350°C 660°F	★★★	★
Tesco • High load • Abrasion-resistant • High temperature	100	0.5	★	★★★	★★	500°C 930°F	★★★	★
PEL®-BH & FAM Spherical Plain Bearing • High load • High surface hardness • Shock, pressure and abrasion-resistant • Reduced maintenance	See Prod Sheet	See Prod Sheet	★★★	★★	★★	250°C 480°F (PEL-BH) 380°C 720°F (FAM)	★★★	★★★



★★★Particularly Adapted ★★Well Adapted ★Suitable hef usa | TJ USA

www.hefusa.net
Phone: 937.323.2556
sales@hefusa.net