Designing with Tufnol Laminates

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TUFNOL

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High Pressure Laminates

As a group of materials, laminated composites have exerted a profound influence on engineering over the last 100 years.

The importance of their properties has ensured their acceptance in a multitude of demanding applications but, for many engineers they provided the first encounter with modern fibre reinforced composites. Development of new laminates using high quality reinforcements with sophisticated resin systems has ensured that laminates have remained at the forefront of engineering technology.

How they are made

Laminates are made by impregnating layers of paper, woven cloth or woven glass with a resin. Many layers are then stacked together in a press and heated under high pressure, which cures the resin and bonds the layers into a solid infusible form.

This is an extremely adaptable process. It allows a wide range of sizes and sections to be produced and it also permits a high degree of control over the constitutes and the proportions in which they are combined. By varying the type of reinforcement used and the type and proportions of resin, a whole family of grades can be produced with properties tailored to meet specific needs. Also by rolling or shaping the impregnated layers prior to pressing, stock shapes such as rods and tubes can be economically produced with the laminates orientated in the correct direction for the application.

The resulting Tufnol laminates combine mechanical and electrical strengths with chemical and weather resistance. They are rigid, with high strength and low weight, and can be used in temperatures from absolute zero to over 250°C.

Engineering with Laminates

Why use them?

At Tufnol, we deal with a very wide range of engineering composites, including thermoplastics, vulcanised fibre and high performance composites, in addition to laminates. As such, we are well able to appreciate the difficulty facing the engineer who wishes to choose the optimum material for a particular application. Technical requirements concerning working environment, material properties and component performance need to be balanced with economic factors related to cost, availability, production methods and so on. Correct material selection is essential to successful performance. The following information is intended to help you to understand how to engineer with laminates.

Key properties

In common with many engineering plastics, high pressure laminates are light in weight, and have good strength with very useful electrical insulating properties. They generally have lower modulus than most metals and are sympathetic to mating metal parts, without being ductile. They do not corrode and can help to prevent corrosion in metal parts. However, they have a higher thermal expansion than many metals and are capable of absorbing a small amount of environmental moisture, which can produce slight dimensional changes. Laminates can also readily be machined to produce components.

In comparison with engineering thermoplastics, laminates generally are more rigid and stronger under flexural, tensile and compressive forces. They can withstand heavy loads with little deformation, and, at normal stresses, creep is minimal, giving load-bearing characteristics superior to those of thermoplastic materials.

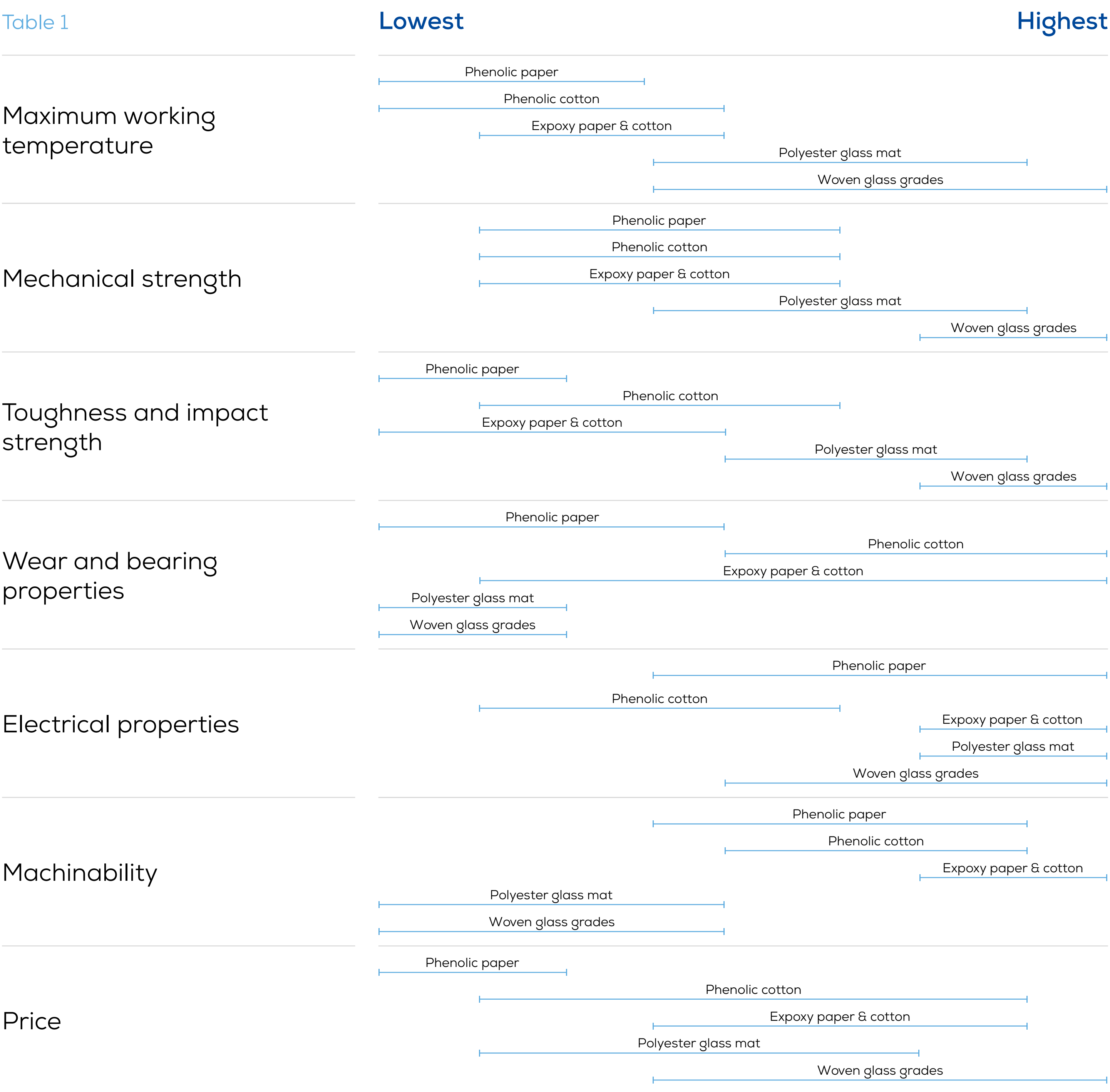
Laminates offer exceptionally wide temperature capability, from cryogenic temperatures to over 250°C, and they are not impaired by repeated cooling and warming. They have particularly good weather resistance and are used in applications requiring very long life in outdoor or marine environments. Chemical resistance to most oils and other hydrocarbon fluids is also good, including most solvents. Concentrated acids and alkalis will attack laminates, but in a dilute form these do not cause appreciable damage.

Tufnol laminates which are reinforced with cotton or synthetic fabrics have excellent bearing properties and are used in a very wide range of wearing applications including some very demanding situations. Water is a very effective lubricant for these grades. This feature is extremely useful, allowing design and operation to be simplified in many applications and processes where water or water based fluids are already present. Some Tufnol fabric grades contain special additives which reduce friction and wear in dry bearing applications. However, the natural cotton fabric grades are often used with water or a conventional oil or grease based lubricant to develop fully their bearing potential.

Choosing the right grade

Tufnol laminates have a wide range of characteristics and it is important to select the correct type for each application. In the following, the grades have been divided into groups and the principal features of each group are described below. These notes, together with the comparison table (table 1) and other data, will help you to focus on the most suitable group for a particular application. The detailed information given in following pages will assist with the choice of a particular grade within the group and the final choice can be confirmed by reference to the specific data given in the remainder of this publication, and in product literature for individual grades.

Table 1



Phenolic paper grades

These materials are strong, rigid and very economical, with good electrical insulation properties.

They are used in a very wide range of electrical installations and in equipment where rigid electrical insulation is required. The higher specification grades are chosen for higher voltage and for greater electrical stability in conditions of varying humidity.

The impact strength of phenolic paper grades is not as high as materials in other groups and they are not usually chosen where toughness, bearing properties or high stress carrying capabilities are required. However, the lowest cost grades in this group represent excellent value as rigid non-metallic materials and this results in their use in a very wide range of less demanding applications.

Phenolic cotton grades

Tufnol phenolic cotton materials are the work-horse grades for general mechanical applications.

They are strong and tough with very good wear resistance and they are easy to machine into finished components. They are available with cotton fabric reinforcements ranging from fine weave to coarse. In general, the medium to coarse weave grades are used for larger and more rugged components requiring good all round strength and toughness. The finer grades are chosen for their superior finish, higher dimensional stability and improved strength in thin sections.

The electrical properties also tend to be higher in the finer grades. However, the Tufnol range includes a medium fabric weave with enhanced electrical properties, suitable for electrical and electro-mechanical applications.

Another special Tufnol grade Tufnol Bear Brand was specially developed for use as a bearing material. It has enhanced wearing properties and dimensional stability, giving excellent performance in a multitude of bearing applications with water, oil or greases as a lubricant.

Epoxy paper and cotton grades

An outstanding feature of the Tufnol range.

These grades are characterised by their excellent electrical properties, particularly their resistance to surface tracking and by low water absorption, good dimensional stability and higher working temperature than their phenolic counterparts. In particular, the fine weave cotton fabric grade offers first class electrical properties with excellent wear resistance, a combination not found in other grades. This material provides a superb machined finish and it is used in many exacting wear applications, where very good dimensional stability is needed.

Polyester glass mat

Polyester resin bonded glass mat laminates are a useful group which fall in price and performance between the phenolic paper grades and the high performance woven glass types.

They are good electrical insulators with higher temperature capability than the phenolic paper materials. They are reasonably strong and rigid and grades with assessed flammability characteristics are included. They are not as easy to machine as phenolic paper grades and would not usually be chosen for wearing applications. Common applications include insulating panels in electrical equipment and similar items.

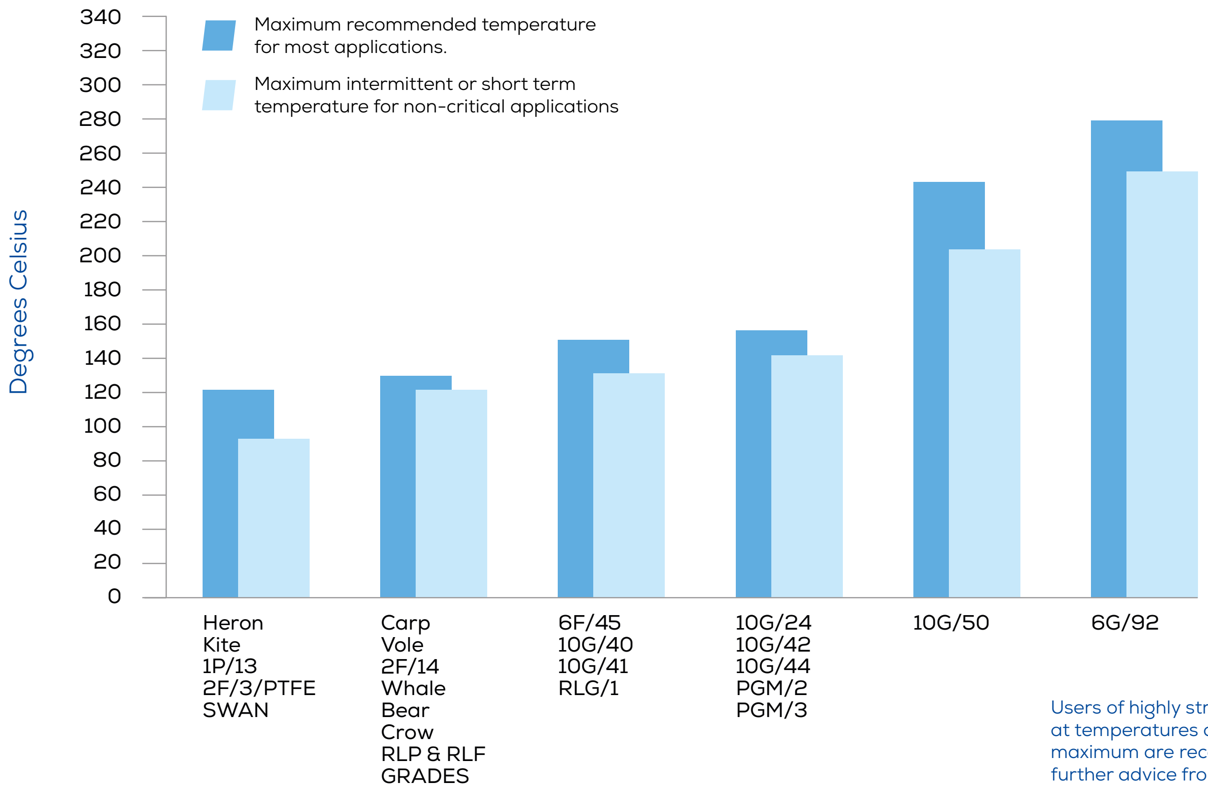
Glass fabric grades

This group includes grades with wide ranging properties determined by the type of resin used to bond the laminations.

All of these materials are characterised by very high strength properties, good temperature resistance and good dimensional stability. Due to their high glass fibre content, they are not machined as readily as cotton or paper grades and are not normally suitable for applications involving wear. The range includes grades with exceptional temperature resistance, first class dielectric properties, good resistance to tracking, assessed flammability and superb structural strength and toughness. These materials are used in a very wide range of technically demanding applications.

Figure 1

Maximum working temperatures of Tufnol laminates



Users of highly stressed components at temperatures approaching the maximum are recommended to seek further advice from Tufnol Ltd.

Designing with laminates

Choice of laminar direction

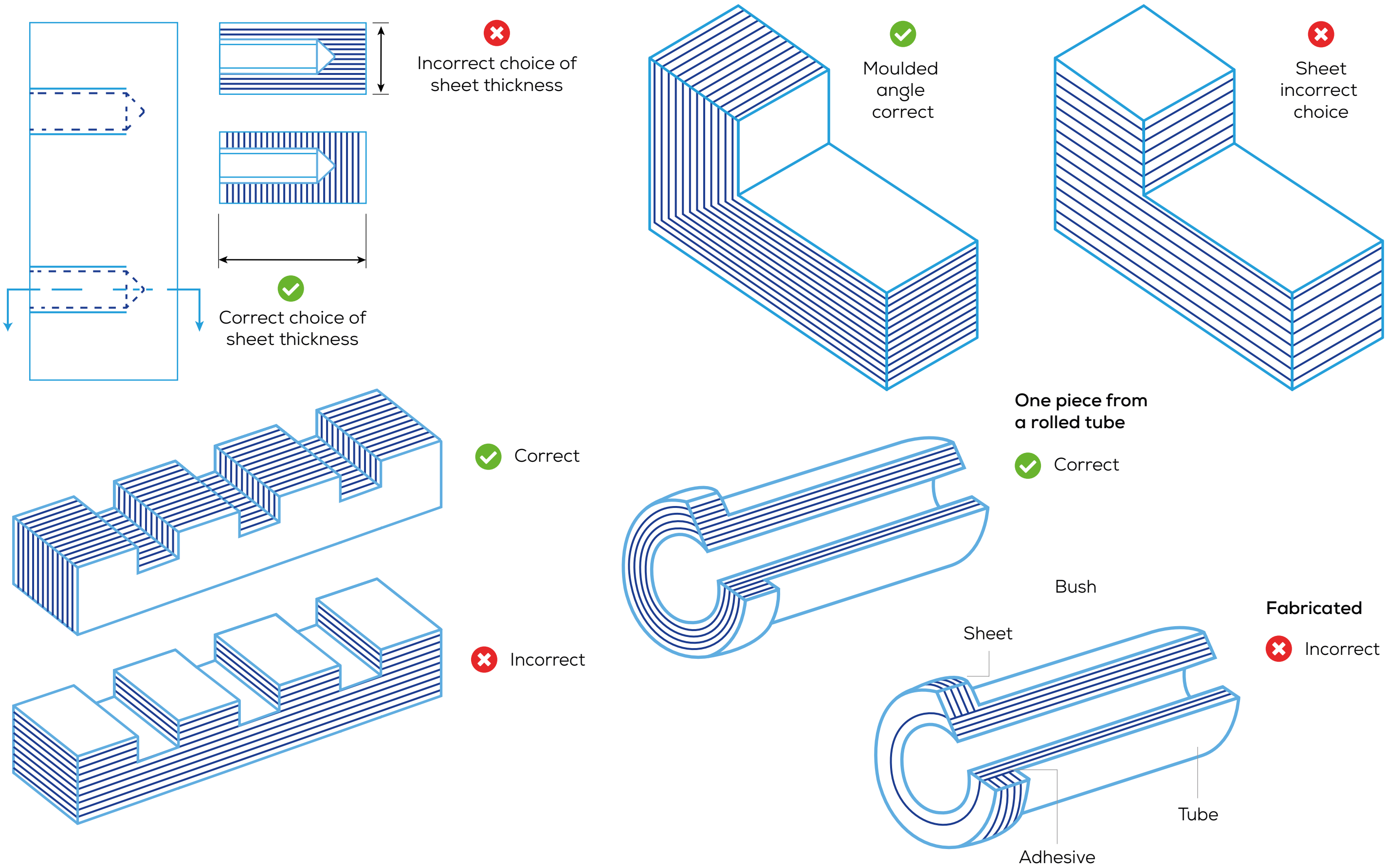
These materials are strong, rigid and very economical, with good electrical insulation properties.

The designer who is considering using a laminate for a particular application should always bear in mind the fact that the material has a laminar structure and therefore has different strengths in different directions relative to the layers. It is therefore essential to ensure that the correct section of the material is chosen, so that the laminations lie in the best direction to deal with the stresses involved. Even where components are not required to withstand any load in use, machining to produce the component itself causes stress. Lack of consideration for the structure of the laminate can lead to fracture during production, handling or transit.

Figure 2 illustrates several examples where the laminar construction has influenced the choice of section away from the most immediately obvious. Many laminates are slightly sensitive to stress concentration and as with other materials wherever possible it is good design practice to avoid stress raising features, such as sharp internal corners or sudden changes in section.

Figure 2

Choice of section for components made from laminates



Tolerances on standard sections

These materials are strong, rigid and very economical, with good electrical insulation properties.

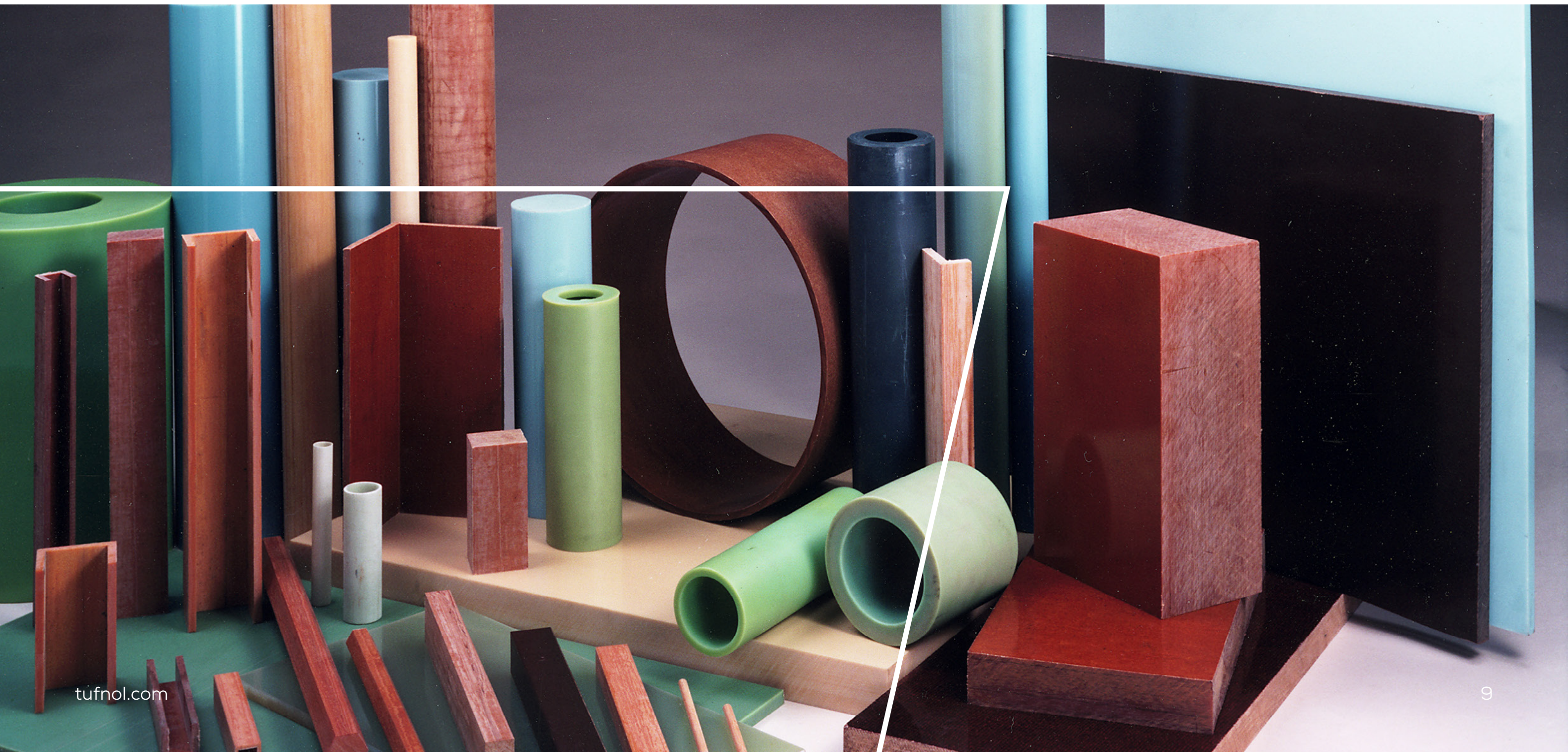
High pressure laminates cannot be moulded to precisely accurate dimensions and when selecting sizes of standard materials for ordering purposes, an allowance should be made for the possible variations in, for example, the moulded thickness of a sheet or concentricity of a rolled tube. These are usually greater with the coarser reinforcing materials and reference should be made to the British Standard relevant to the particular type of laminate.

Machining tolerances and finishes

Owing to the nature of the material, components cannot normally be machined to the finest tolerances achievable with metals.

However, the surface of a laminated composite component has a slight resilience which usually renders very fine tolerances unnecessary for good fits to be achieved. Laminated bushes require a greater interference than metal bushes so that the same machining tolerance becomes much less significant. On the other hand, when inserted, the laminated bush may compress slightly on the bore, so an allowance may have to be made for this when determining the size to be machined.

Similarly, the fibrous nature of the reinforcement causes considerable difficulty in achieving the fine surface finish readings on machined faces. This obviously varies with different grades but, for example, a first class milled face on a medium weave fabric laminate may record a surface finish of 3 to 4 micrometres (125 to 160 microinches) and even prolonged polishing may only reduce these figures by half. Once again, the resilient surface of the laminate usually makes fine finishes unnecessary. The milled face mentioned above would be entirely suitable as a bearing surface, without polishing.



Machining Tufnol

Machining has always been the ideal production route for low-run and prototype components, ranging from the precision requirements of the aircraft industry to large scale components for off-shore installations.

Tufnol has, for may years, invested heavily in their in-house machining facilities and has established one of Europe's largest machining centres, through which millions of components pass each year. Engineers at Tufnol are able to advise on both materials and the most efficient machining methods for the particular component, thus helping to cut unit costs.

In the following paragraphs, guidance is given to those wishing to machine their own components in-house.

General Principles

Tufnol engineering composites are readily machined on normal tools and the usual operations can be carried out satisfactorily.

Some adjustments to tool forms and techniques are required to obtain the best results but, as a guide, the procedures are basically similar to those used for brass, with tool angles amended to reduce heat generation. The thermal conductivity of composites is much lower than metals and if heat build-up is allowed it will impair the production of accurate, burr-free components.

In the case of laminates, care should be taken to choose the form best fitted for the job, e.g. gears should be cut from sheet, not rod, and it is essential to clamp the workpiece when drilling in line with the laminations. Maximum strength is obtained with holes at the right angles to the laminations.

A good machinist will soon become competent in machining Tufnol but the following notes on general practice will help.

Tools

Tools must be kept sharp at all times. Dull tools generate heat, cause poor surface finish and create difficulty in achieving tolerances.

Use correct tool shape

Ample clearance must be provided to ensure the cutting edge only is in contact with the workpiece. Tools should be ground to suit the machining of composites and wherever convenient should be reserved for this purpose, particularly where the component is for an electrical application.

General Principles

Use correct tool steels

High speed steel tools give a first-class finish and are suitable for small production runs. For long runs, tungsten carbide tipped tools are preferable, to obtain a better tool life. For the glass reinforced grades, carbide tips may be used for small scale machining but, where large amounts of machining are involved, diamond tools should be used.

Keep tools free from swarf

Particularly when drilling and tapping. A slogged tool rapidly generates heat which will affect the quality of the work. When drilling, the use of the 'woodpecking' technique to clear the swarf is recommended.

Use correct feeds and speeds

In general, high speeds with a slow feed are required, whilst avoiding the generation of heat. A fairly light finishing cut will give a better surface finish. Best results will be obtained using a light cut at all time. Lower feed rates are advisable for glass grades.

Support the workpiece

Where necessary a backing or support should be used to prevent deflection due to tool pressure. To obtain a perfectly clean edge when cutting TUFNOL laminates across the layers, they should be backed with a similar material.

Machine dry

For most purposes, Tufnol laminates are machined dry but where especially fine finish is required a small quantity of light mineral oil may be applied. When machining a component intended for electrical purposes lubricants should be used with discretion as some lubricants may impair the electrical properties of the material.

Control Dust

As Tufnol laminates are normally machined dry, dust is created. It is therefore advisable to use dust extraction equipment when these materials are to be machined, to ensure that occupational exposure limits to dust are met. When machining glass-based materials, the swarf may cause irritation of the skin. This is best avoided by preventing contact or by speedy removal with soap and water.

The Company's recommendations regarding the handling, storage, machining and disposal of its products are contained in their Health and Safety publication which is freely available on request.

Drilling

Standard twist drills can be used but it may be necessary to vary the point angle to suit the material thickness (See Figure.3).

The included angle should be such that the full diameter of the drill has entered the hole before the point breaks through. The positive rake should be removed to prevent lifting the laminations and the land removed to improve the flow of swarf. When drilling holes, frequent drill clearance, using the 'woodpecking' technique is essential. For recommended speeds and feeds. (See Table 2)

For large holes in sheet, a wing or fly cutter can be used, with a small pilot hole for guidance. This also applies to trepanning which can be carried out with standard wing trepanning cutters.

Holes to be tapped should be drilled slightly oversize on core diameter and open ends chamfered slightly. Due to resilience of the materials, a drilled hole will close-in slightly when the drill is withdrawn.

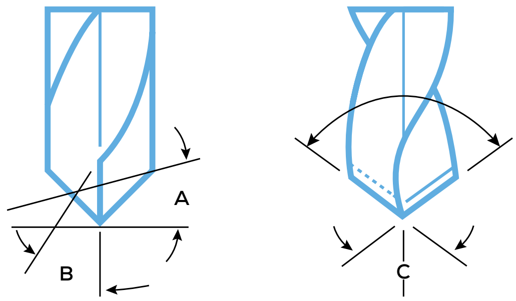
Drill Recommendations

Figure 3

A 9° to 15°

B 0° to 5° Pos

C 80° to 110°



Gear cutting

Gear teeth can be cut on a milling machine or gear shaper with the usual cutters and tools. .

Speeds and feeds vary with the shape and size of teeth, but 43m/min (140ft/min) is a good average peripheral speed when a high-speed milling cutter is being used.

The feed should be reduced to 15m/min (30ft/min) for cutting steel shrouded gears. If securely clamped and backed, unshrouded gears can be cut in banks.

Sheet material must be used for gears cut from TUFNOL laminates.

Grinding

Centreless grinders are suitable for grinding tube or rod sections. This is done dry using an average diameter reduction of 0.25mm (0.010") per run.

Grinding wheels must be kept from clogging and the surface should be trued periodically.

Guillotining

TUFNOL laminated sheet can be cut on a power-driven guillotine.

The maximum thickness for guillotining and the moving blade angles should be as stated in Table 3. The cutting edges of blades must be kept clean.

Knurling

Laminates cannot be readily knurled. Machined grooves will give a similar effect.

Milling

Milling of TUFNOL laminates can be carried out on plain or universal millers or on spindle moulders, the former ones being recommended where a considerable amount of material has to be removed. Spindle moulders are preferable when removing small amounts of material using cutters with straight or spiral teeth – the latter gives a smoother finish.

Tooth pitch should not exceed 16mm (5/8”) for a 100mm (4”) diameter cutter. A maximum depth of cut of 1.5mm (1/16”) and cutter surface speed of 1220-1830m/min (4000 – 6000 ft/min) should be used.

Approximate speed guide for high speed steel drills

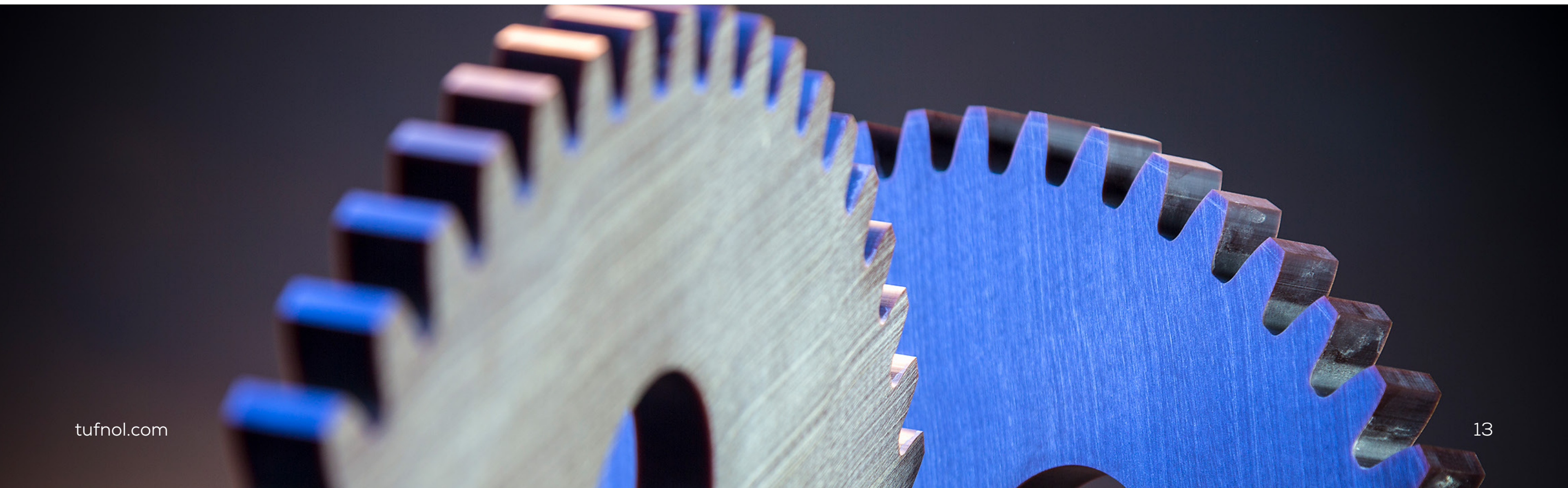
Table 2

Drill Diameter	Revs/Min	Feed
1/16" (1.5mm)	7500	0.006" (0.15mm) to 0.008" (0.20mm) per rev
3/16" (5mm)	2500	
¼" (6.4mm)	2000	
½" (12.7mm)	1000	
¾" (19mm)	700	
1" (25.4mm)	500	

Recommendations for guillotining

Table 3

	Maximum Thickness	Blade Slope
Paper Base	0.040" (1mm)	3/16" in 4ft (4mm in 1m)
Fabric Base	3/32" (2.4mm)	1" in 4ft (20mm in 1m)
Glass Base	3/32" (2.4mm)	1" in 4ft (20mm in 1m)



Punching

Most grades of TUFNOL laminates can be punched on hand or power presses in thicknesses up to 3.2mm (1/8”).

It is advisable to heat all the paper-based materials, but the majority of the other brands may be punched cold up to 1mm (0.040”) thick, above which they require heating. Delicate or complicated shaped components should be heated in any thickness.

Thermostatically controlled heating of the scrip to a maximum of between 80°C and 90°C is recommended for all grades, which punches well at temperatures from 60°C to 80°C. The material should not be continually reheated as this causes brittleness.

Unlike metals, laminates are not malleable, and the punching operation snaps the material instead of ductile shearing or pushing it apart. Some cavitation may therefore occur, particularly on thicker material. Maximum support must be given to the strip during punching. A stripper plater can be used for thin material, but best results are obtained using a rubber pressure pad. Ample clearance must be allowed for the rubber to close-in under compression.

The punch must be perfectly smooth and set to enter the die not more than 0.13mm (0.005”) at the end of its stroke. The die must also be smooth and relieved. The maximum clearance between punch and die should not exceed 0.05mm (0.002”). Tools must be kept clean and free of swarf or dust.

Recommended punching methods and minimum clearances for Tufnol laminates

Table 4

	Can be punched cold without pressure pad		Must be heated before punching; pressure pad necessary		
Thickness	1/64" (0.4mm)	1/32" (0.8mm)	1/16" (1.5mm)	3/32" (2.4mm)	1/8" (3mm)
Dimension X	1/8" (3mm)	1/16" (1.5mm)	3/32" (2.4mm)	1/8" (3mm)	3/16" (3mm)
Dimension Y	3/32" (2.4mm)	3/32" (2.4mm)	3/32" (2.4mm)	1/8" (3mm)	3/16" (3mm)

Riveting

This can be undertaken by conventional methods, but metal washers may be necessary to allow for spreading of the rivet ends. Rivet holes should be drilled to provide a light tap-in fit. It is not advisable to drill holes undersize. The distance from the outside of the rivet hole to the edge of the material should be at least twice the diameter of the rivet.

Routing

TUFNOL laminated sheet can be cut on a power-driven guillotine.

Tufnol laminates can be routed using double edge cutters at speed between 18000 and 24000 rpm. Tungsten carbide tipped cutters are advisable when routing paper based grades, whilst diamond-cut burrs are recommended for glass grades.

Sawing

Production work is best undertaken with circular band, or fret saws but the work should not be forced into the blades. When required, these materials can be cut with coarse pitch hacksaws.

Circular Saws

The teeth for cutting Tufnol laminates are generally of the hand saw shape. These saws should have a tooth pitch of around 12mm (1/2") and a set of 0.7mm (0.025") each side. If the set is reduced to give a finer finish, extra care is required. Carbide tipped saws give the best results. They can be used for thin sections of glass grades but for large quantities and thicker sections of these grades, diamond saws are essential.

Recommended peripheral speed of saw; from 1525mm to 2300mm per min (from 5000 to 7500ft per min). (See Table 5)

Cutting guide for circular saws

Table 5

Thickness of Laminate	Diameter of saw	No. of teeth per inch (per cm)	Approx r.p.m.
up to ¼" (up to 6mm)	8" to 11" (200mm to 280mm)	9 to 11 (3½ to 4½)	2500 to 3000
over ¼" up to 1" (over 6mm up to 25mm)	10" to 12" (250mm to 300mm)	6 to 9 (2½ to 3½)	1500 to 2000
over 1" up to 3 ⁹⁄₁₂" (over 25mm up to 90mm)	14" to 18" (360mm to 460mm)	3 to 4 (1 to 1½)	1400 to 1600
over 3½" up to 6" (over 90mm up to 150mm)	18" to 24" (460mm to 600mm)	2 to 3 (¾" to 1)	1200 to 1500

Band Saws

For Tufnol laminates, raker or skip tooth band saws should be used with teeth set 0.7mm (0.025”) each side. The saw width may range from 10mm (3/8”) to over 25mm (1”) dependent on material, thickness and curve required. (See Table 6)

Cutting guide for 30" (720mm) band saw

Table 6

Thickness of Laminate	Approx r.p.m. of 30 in. (760mm) wheel	Approx saw speed ft/min (m/min)	No. of teeth per inch (per cm)
⅛" up to ¼" (3mm up to 6mm)	700	5500 (1680)	10 (4)
over ¼" up to 8" (over 6.4mm up to 200mm)	200	1580 (480)	4 (1.5)

Jig and Fret Saws

A suitable working speed for a light jig saw of 4 ½ teeth per cm (11 teeth per inch) for cutting Tufnol laminates is 500-600 cutting strokes per minute.

Working speeds of 500-600 strokes per minute should also be used for cutting laminates up to 6mm (1/4”) thick on a fret saw using No.10 blades.

Tapping

This operation can be done by hand or by machine. It is advisable to drill the hole slightly oversize and to include a small chamfer at the open ends. With blind holes it is necessary to remove all swarf before tapping.

For tapping holes in Tufnol laminates from (M4) to (M13) using a drilling machine or capstan and ground thread plug taps – taper taps are unnecessary – the tapping speed is 200 rpm with a clearing tap speed of 750 rpm.

Automatic tapping machines and tungsten-carbide or treated taps are an advantage.

High speed taps should be 0.05 to 0.13mm (0.002” to 0.005”) oversize and spindle speeds below those for drilling and turning are recommended.

Threading

It is advisable to make external diameters very slightly below nominal, and internal diameters very slightly above nominal. Self-opening die heads with ground thread chasers and negative rake dies give satisfactory results but single point tools or chasers can also be used. For these, the top rake should be zero to negative and the starting and finishing cuts light.

Turning

Conditions will vary with the size and form of Tufnol laminates but generally, tipped tools at high speeds with light finishing cuts give good results.

For instance, a feed of 0.1 – 0.15mm (0.004" – 0.006") per rev with a peripheral speed of 185m/min (600ft/min) will provide a first class result. For general work, a tool with no top rake but with side and front clearances of 10° to 15° is satisfactory. (See Figure 4)

For heavy cuts, when turning laminated sheet, high speed tools with a positive rake of 0° to 20° can be used. Gear blanks, washers and similar items of identical size can be turned in banks, tightly clamped with the end piece suitably backed up.

Bonding Tufnol

Bonded joints can be very successfully produced with Tufnol laminates using two part epoxy adhesive. The adhesive chosen should be suitable for the conditions which will be met in service, especially with regard to operating temperature.

Araldite 2019 epoxy adhesive has been found useful for general purposes where the application temperature is not expected to exceed about 50°C. This adhesive spreads easily over large areas of joint and will cure successfully at 20°C given adequate time. Araldite 2011 is more viscous at room temperature, which can be advantageous for certain types of joints e.g., those with small gaps or fillets. It will also cure at 20°C or over and, when fully cured, it can operate at temperatures up to 60°C.

When higher service temperatures are required Araldite 2014 and Permabond E3524 have both given good results with recommended maximum service temperatures of 120°C and 150°C respectively. For even higher temperatures, choice of adhesive needs to be carefully matched to requirements. For example, Eccobond 104 has been used to produce strong joints for service at over 230°C but, in manufacture, the joint needs baking at high temperatures which makes it suitable only for the most heat resistant of Tufnol grades.

Especially at higher operational temperatures, the use of an adhesive and the nature of the joint should be carefully considered in the light of the service life required. The effects of other conditions, such as differential expansion, should be borne in mind. It is worth noting that the thermal expansion of Tufnol is anisotropic with expansion through thickness greater than in the plane of the laminations. In critical applications or where joints are to subject to severe stresses, it is preferable to incorporate some form of mechanical fixing.

Tufnol, is frequently bonded to metals or other materials. Some metals require special surface preparations or pre-treatment and the adhesive manufacturers' recommendations should be sought.

Adhesive manufacturers' recommendations for storage, safe handling, mixing and curing etc., should be followed carefully.

Consistent quality of joints arises from good procedures in production, with accurate mixing and attention to detail. Mating surfaces must be clean, dry and entirely free from dirt, oil and grease. Where necessary, the material should be abraded to provide a good key for the adhesive. Space should be allowed between the mating surfaces for the adhesive and the joints should be lightly clamped during curing. Spigot location is also recommended for bobbins, flanges, and similar features as it makes accurate assembly much easier.

Araldite, Permabond and Ecobond are registered trade marks and the adhesives mentioned should be available from good suppliers.

Figure 4

Turning tool recommendations

Roughing

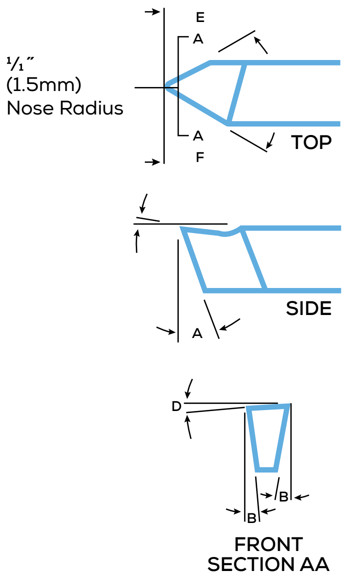
A	15° to 30°
B	10° to 15°
C	0° to 20° Pos
D	0° to 5°
E	40° to 50°
F	45°

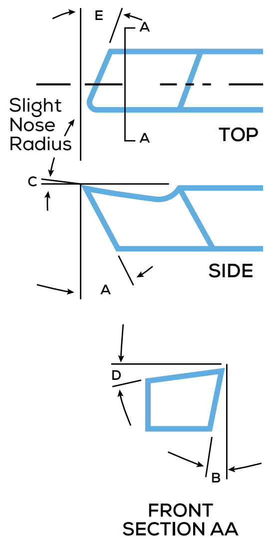
Finishing

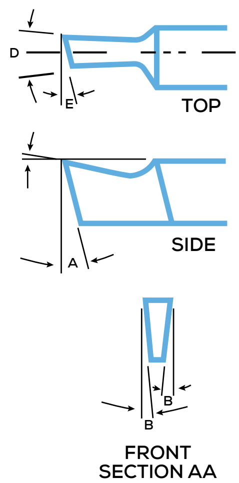
A	15° to 30°
B	5° to 10°
C	0° to 20° Pos
D	0° to 5°
E	15° to 20°

Part-off

A	15° to 30°
B	5° to 10°
C	0° to 10° Pos
D	4° to 10°
E	0° to 20°







Bearings from Tufnol cotton fabric laminates

The designer who is considering using a laminate for a particular application should always bear in mind the fact that the material has a laminar structure and therefore has different strengths in different directions relative to the layers. It is therefore essential to ensure that the correct section of the material is chosen, so that the laminations lie in the best direction to deal with the stresses involved. Even where components are not required to withstand any load in use, machining to produce the component itself causes stress. Lack of consideration for the structure of the laminate can lead to fracture during production, handling or transit.

Lubricated bearings

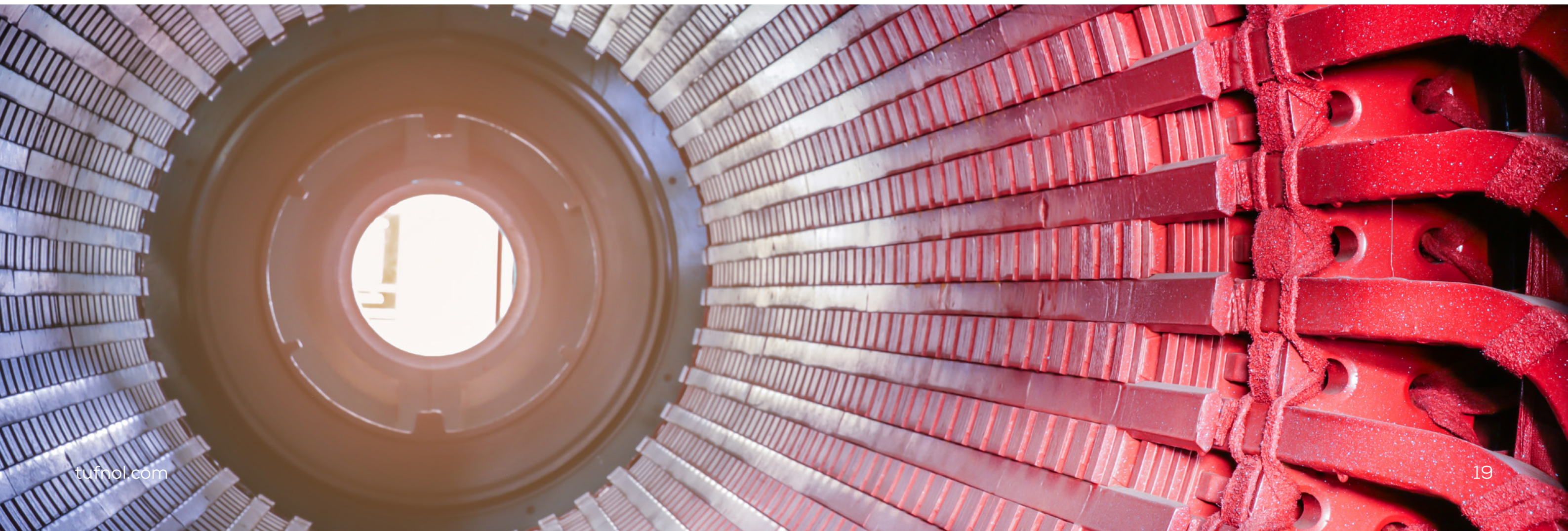
The ability of Tufnol materials to be effectively lubricated with water is particularly useful.

In many applications, design has been simplified and cost reduced because the Tufnol bearing could be lubricated by the fluid in which it was operating, eliminating the need for sealed bearings with oil or grease inside. Although Tufnol laminates are used dry in a great many less demanding applications, most Tufnol cotton fabric bearing materials are not self-lubricating and it is preferable to use a lubricant to develop their full bearing potential. Properly designed and lubricated Tufnol bearing surfaces give excellent service for many years and are frequently a most cost effective choice. The cotton fabric are grades most commonly selected for wearing and bearing applications up to about 120°C. As with all applications, the final selection of grade should be based on a broad understanding of the requirements of the job, including such factors as temperature, pressure, velocity, shock loading, lubrication, and the degree to which the bearing will be expected to tolerate detrimental factors, such as deterioration of working environment during its life.

Dry bearings

For cases where a material is required for a dry bearing application, one particular grade of Tufnol is offered which does have self-lubrication capabilities. Tufnol grade 2F/3/PTFE is a cotton fabric laminate which contains finely divided particles of PTFE powder distributed throughout the material. This combines the mechanical strength, rigidity and toughness of a laminate with the self-lubricating and low friction characteristics of PTFE.

In addition, where required Tufnol can offer a wide range of other engineering plastics such as Nylon, Acetal, PETP and polyethylene and will be happy to give advice on material selection.



Performance

Many factors influence the performance of a bearing. Pressure, rubbing speed, surface finish, temperature and lubrication all contribute and a change in one of these can often cause changes in one or more of the others. This makes precise prediction of friction and wear extremely complex. To assess suitability of a dry bearing, a common approach is to simplify the problem by considering the PV factor of the bearing. The PV factor for a particular application is obtained by multiplying the working pressure by the velocity. This is then compared to a maximum PV factor for the material. This maximum PV factor is derived from experimental data recorded over a range of conditions and it is usually also adjusted for different conditions of ambient temperature and humidity. For properly designed and operated dry bearings, this provides a very useful rule of thumb assessment but when a lubricant is introduced, a whole new set of factors come into effect. In well lubricated bearings, very high PV factors can be tolerated, and this simplified approach to performance assessment becomes unworkable.

Operating temperature is important in many applications and with dry running bearings in particular it is often the factor which limits performance. This is especially true of thermoplastics bearings, where load capacity depends on the temperature rise and the allowable degree of deformation at the working temperature. This is less applicable to laminated plastics bearings, which do not creep appreciably at normal working loads but it is, of course, still important to keep the operating temperature well within the capabilities of the material. At high loads and speeds, the cooling function of a lubricant becomes especially important, and, in some applications, it is not uncommon to obtain very high bearing performance by circulating lubricant through the bearing under pressure.

Bearing design

General principals

Dimensions

Design of Tufnol bearings follows conventional engineering practice and, in many cases, Tufnol can be used to replace another material.

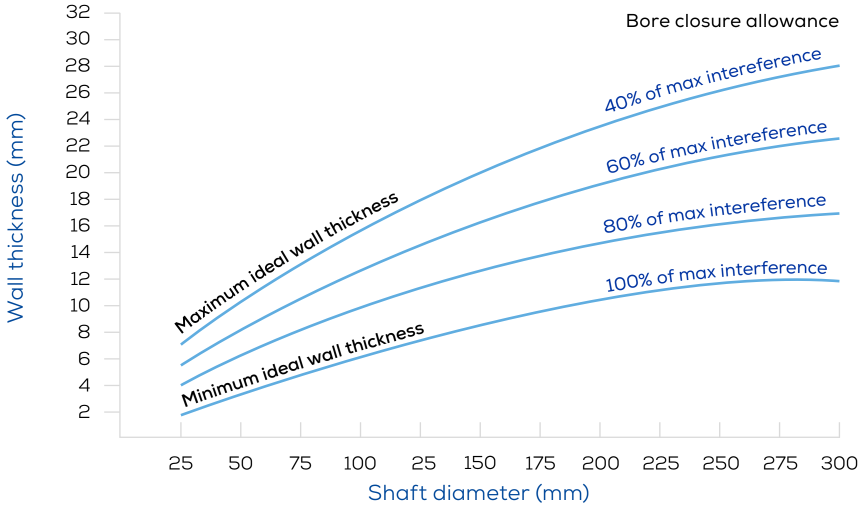
A length of shaft diameter ratio of 1:1 is considered generally ideal because long bearings (over 2:1) can contribute to the build up of heat, which is the main enemy of composite bearings. Allowance should be made for the dimensional movement which can take place due to changes in the temperature and moisture content of the material.

Laminates are able to absorb a small amount of water and, when they do, slight dimensional changes take place. These changes are predictable and it is essential that the initial clearances in a bearing allow for this dimensional change in line with the recommendations given in figure 8 and table 7.

The housing should be designed so that the Tufnol material is fully supported and any grooves which are included should not excessively weaken the wall of the bearing. As general rule of thumb, depth should not exceed one third of the wall thickness. Normally, to assist heat dissipation, excessive wall thickness should be avoided but, where high shock loads are expected, an increased thickness of bearing material is usually preferred.

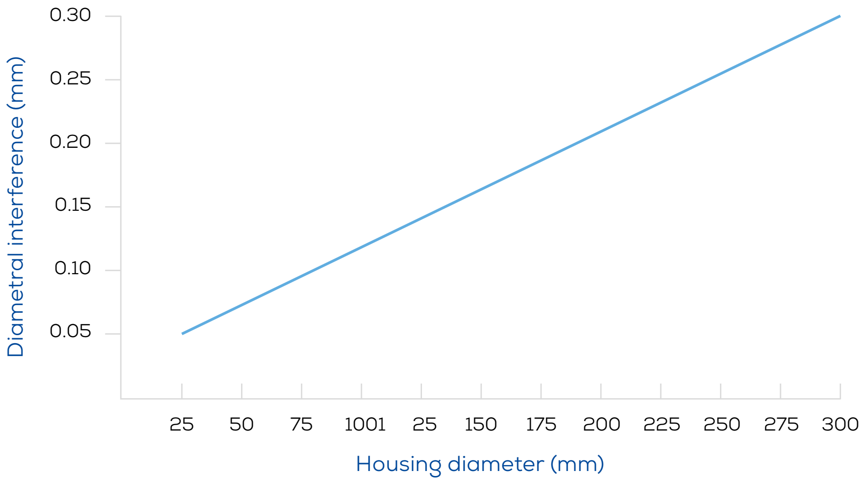
Recommended wall thickness for bearings

Figure 5



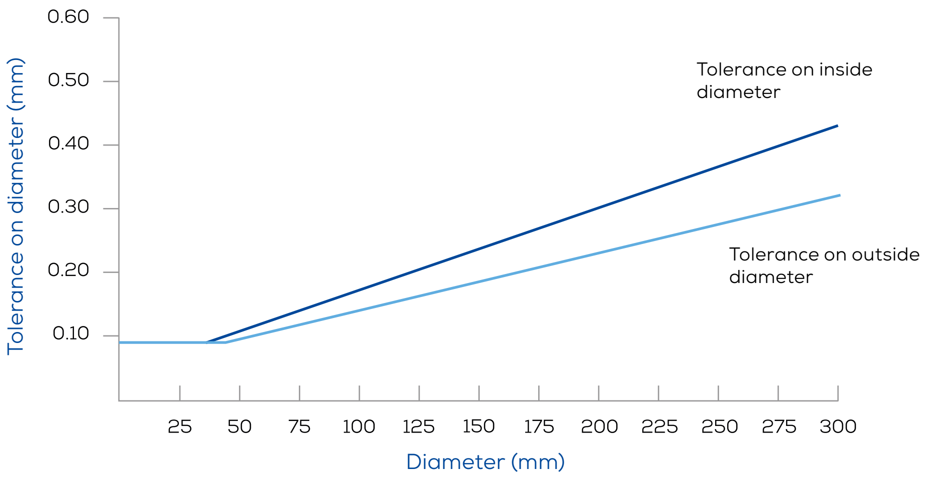
Recommended minimum interference fit

Figure 6



Minimum machining tolerances on diameters

Figure 7



Fixing methods

Although press fitting is the most commonly used fixing method for small cylindrical bearings, when temperature and moisture content are likely to vary widely in service, it is inadvisable to rely solely on an interference fit and some form of mechanical fixing is then preferred. In fact, where a cylindrical bearing is required with minimum initial clearance, positive fixing is usually recommended, as this allows closer control without machining in-situ. Typical fixing methods include keys, set screws, pegs, flanges with screws or adhesive bonding. However, it is important not to use a method such as grub screws which can distort the shape of the bearing and cause binding on the shaft.

Flanges required for location purposes can be provided in several ways. If the required flange diameter is a little greater than the outside diameter of the bush itself, it is usual to produce the flanged bush in one piece from oversized material. However, for greater flange diameters, this would involve greater wastage of material and therefore fabricated components are generally preferred. In such cases, the flange is produced from Tufnol sheet material and a step is machined on the outside diameter of the bush (See Figure 2). The flange is then cemented on to the end of the bush, using a high strength epoxy adhesive. In the majority of cases, this is perfectly adequate, but where very arduous duty is anticipated, an even stronger flange joint can be achieved by machining screw threads in both Tufnol components and screwing the flange on to the bush after coating the threads with epoxy adhesive. Flanges produced from sheet material offer maximum compressive strength, in view of their more suitable direction of laminar structure and bushes with fabricated flanges are therefore very successful.

Where bearings are to be press fitted, the dimensions should be calculated in line with the recommendations given below, taking care to allow adequately for closure of the bore due to the interference of the outside diameter. The bush or housing should be made with a lead chamfer to avoid damage to the bush while it is being pressed in.

Slideways

Dimensional movement may also need to be catered for when designing slideways or wear strips.

Although the dimensional movement of a laminate is proportionally much less in the plane of the laminations than through the layers, long slideways should not be just fixed at the ends or dimensional movement can cause buckling. Wear strips would typically be held every 100 to 150mm along their length by screws or rivets with heads recessed well below the surface.

Dimensional stability

Table 7

Grade	Increase in dimensions after prolonged immersion	
	In plane of laminations	Normal to plane of laminations
Bear, Carp	0.30%	2.50%
Whale, Vole, 2F/14	0.35%	3.00%
Crow, 2F/3/PTFE	0.40%	3.50%
6F/45	0.20%	1.70%

Lubrication

The type of lubrication chosen to suit the application may range from none at all, or perhaps a slight smear of grease on assembly, up to a fully designed circulating system with copious supplies of filtered lubricant pumped under pressure.

Most of the common lubricating oils and greases are suitable for use with Tufnol. Water is also an excellent lubricant and so are many water based fluids, provided that they are not chemically corrosive and do not contain abrasive solids. Many examples exist of Tufnol bearing successfully lubricated by process fluids such as inks, dyes, cleaning fluids, metal treatment solutions, effluents, coolants, and the like.

Grooves are used to help distribute lubricant, and can also be beneficial in providing an escape route for any dirt or wear debris which could otherwise accumulate. Generally, it is preferable to design grooves in simple shapes for even distribution of lubricant, as complex patterns are not required. Obviously, grooves should not be placed in the most heavily loaded areas of the bearing, and should not interfere with the beneficial build up of lubricant pressure between bearing, and shaft under hydrodynamic conditions.

Mating services

For optimum performance, a hard smooth mating surface is preferred.

Surface finishes in the range of 0.4 to 0.8μm CLA are commonly accepted and mating materials such as hardened steel, hard chrome plated or stainless steels or gun metal are often used. Surface hardness better than Rockwell C50 is usually considered ideal but Tufnol laminates are reasonably tolerant and softer shaft materials have given good service in a great many bearings where the loads and speeds were not exceptionally high.

In some cases, mating materials made from other plastics have been used. Whilst this may be acceptable for special purposes, heat dissipation from the rubbing surfaces is restricted and it is not an ideal arrangement.

Tufnol Grade 2F/3/PTFE

Tufnol grade 2F/3/PTFE, a unique dry-bearing laminate was developed as a result of a comprehensive research programme by the Tribology Unit of Tufnol laboratories.

It is a cotton fabric reinforced laminate internally lubricated by very finely divided particles of PTFE uniformly distributed throughout the material.

As a thermoset material incorporating a thermoplastics lubricant it provides advantages derived from both materials, successfully combining the excellent mechanical strength, rigidity, toughness, and good machining characteristics of phenolic laminates with the self-lubricating and low friction properties of PTFE.

Components in a wide variety of shapes and sizes can be easily machined and the uniform distribution of PTFE throughout the laminate ensures that, whatever the shape, PTFE will be present at the bearing surface. This high-performance dry bearing material has many applications in manufacturing industries, where non-contaminating, silent running, long-life bearings are required.

Grade 2F/3/PTFE can be used continuously at temperatures up to 100°C and retains sufficient of its properties to be useful at temperatures approaching absolute zero. Under high stress, its creep and cold flow properties are superior to those of thermoplastics bearing materials. The frictional properties of Grade 2F/3/PTFE are quite outstanding in dry bearing applications.

Calculating Dimension

Where Tufnol is replacing an existing bearing, the basic dimensions of shaft and housing will usually be fixed. Tufnol bearings can range in size from very small machined items to very large bearings fabricated from a number of parts. Moulded Tufnol tubes are produced up to 9" (228mm) outside diameter and Tufnol rolled laminated tubes are made up to 26" (660mm) outside diameter. Both types of tube in cotton fabric grades have good wear resistance. Moulded tube is usually preferred for bearings, whilst rolled laminated tubes are often used for items such as split wear rings, piston rings, and other similar applications, where good concentricity or toughness is required with a thin wall section. Calculation of bearing sizes should follow the method shown in the following example to ensure that clearance in the bore is adequate to prevent seizure.

Note that the variation in bore clearance can be quite substantial when an interference for is used as it arises from the sum of the machining tolerances on the shaft, housing and the inside and outside of the bearing. As a result, this type of fit often requires machining tolerances to be the minimum practicable. Some sizes of bush can be machined by a method which allows for an accurate tolerance on wall thickness to be maintained. However, where a minimum variation in clearance is required, bearings are bored after fitting into the housing.

Data Required

Proposed nominal wall thickness (see fig 5 if required).
Proposed shaft diameter and tolerance.
Proposed bearing length.

Compile and calculate

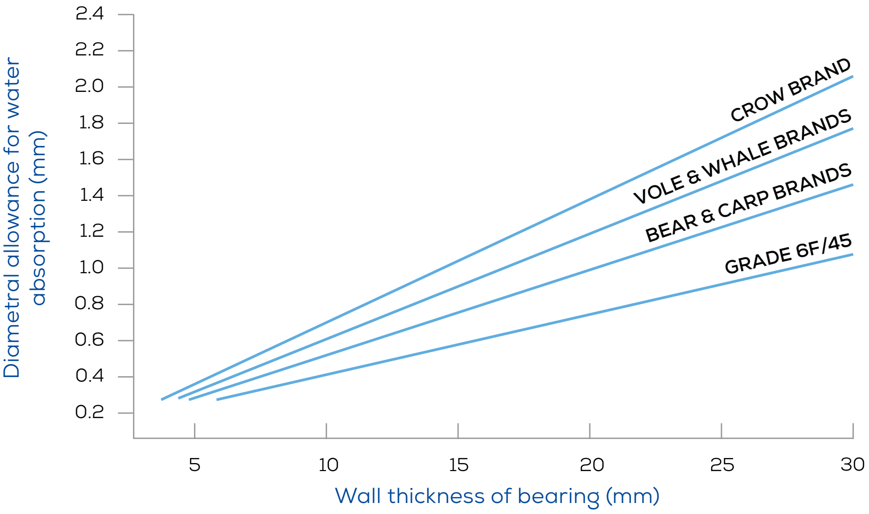
Table 8

Max housing diameter	Ⓐ
Interference fit (if required) *(Figure 6)*	Ⓑ
Min bearing o.d. Ⓐ+Ⓑ	Ⓒ
Machining tol. on bearing o.d. *(Figure 7)*	Ⓓ
Max bearing o.d. Ⓒ+Ⓓ	Ⓔ
Minimum housing diameter	Ⓕ
Maximum interference Ⓔ–Ⓕ	Ⓖ
Expected bore closure % *(Figure 5)*	Ⓗ
Maximum actual bore closure Ⓗ% of Ⓖ	Ⓙ
Swelling allowance *(Figure 8)*	Ⓚ
Thermal expansion allowance *(Figure 9)*	Ⓛ
Minimum final running clearance *(Figure 10)*	Ⓜ
Maxmimum shaft diameter	Ⓝ
Min bearing i.d. Ⓝ+Ⓜ+Ⓛ+Ⓚ+Ⓙ	Ⓟ
Machiningh tolerance on bearing i.d. *(Figure 7)*	Ⓠ
Maxmimum bearing i.d. Ⓟ+Ⓠ	Ⓡ

TUFNOL

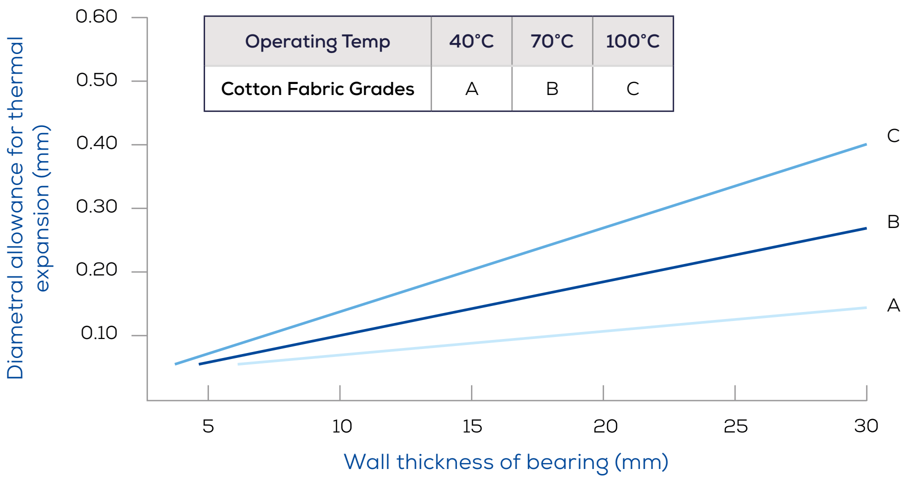
Allowances for absorption of water

Figure 8



Allowances for thermal expansion

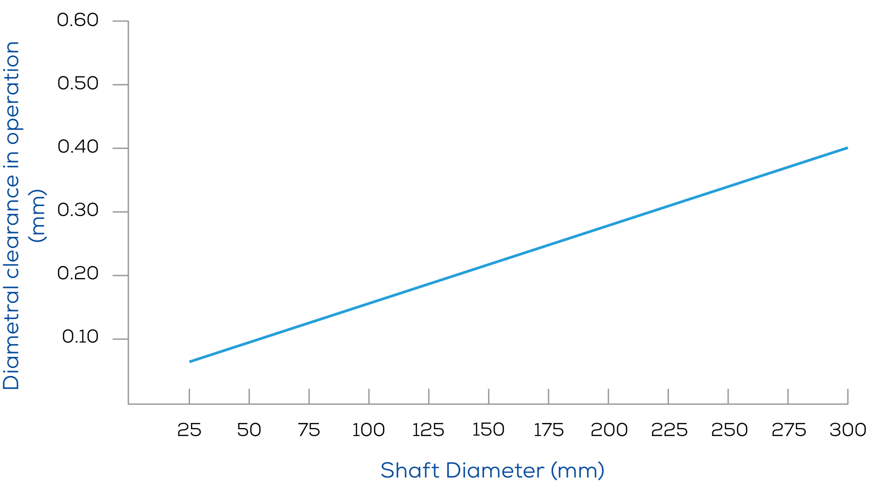
Figure 9



Operating Temp	40°C	70°C	100°C
Cotton Fabric Grades	A	B	C

Final running clearance

Figure 10



The mechanical strength of base laminate combines with the frictional properties of the PTFE dispersion to give grade 2F/3/PTFE a wear resistance which is many times greater than that of either of these materials individually. This allows it to be used with confidence at loads and speeds which would be considered prohibitive for many other dry bearing materials.

The Tufnol technical advisory service is available to provide any further information which may be required.

Stave type bearings

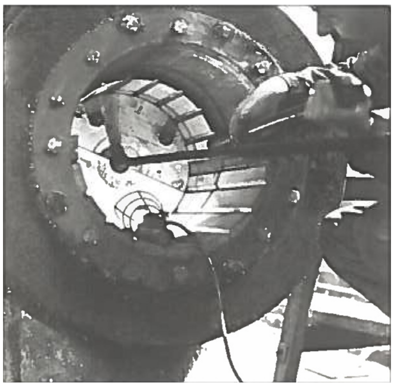
For many years, Bear Brand Tufnol has been used for water lubricated bearings in marine applications. Bear Brand Tufnol stern tube and rudder bearings have been installed on a great many vessels of all sizes and are approved by the major marine classification societies.

For large bearings it has been controversial practice to make stave type bearings, where the housing is lined with machined strips cut from sheet to form the bearing (See Figure 11).

These strips or staves are held in place by being wedged between key strips which are secured to the bore of the housing. When fitting, the last stave to be inserted between a pair of key strips is usually trimmed on width to give a tight wedge fit and is then driven in to hold all of the staves in place. By machining chamfers on each stave, when assembled, grooves are formed which allow transport of the water lubricant into the bearing.

Two types of water grooves are illustrated in figure 12 and these are produced by simply machining the edge of each stave. The UV shaped groove suffers less area reduction due to bearing wear, its rounded base encourages a more efficient sourcing effect to remove sand particles, and the chamfers adjacent to the bore encourage the formation of a water film between the bearing and shaft. The UV shaped groove is recommended for stern tube bearings. The simple V shaped groove is usually adequate for rudder bearings.

Figure 11



The entry of sand into stern tube bearings can be prevented to a great extent by the provision of a water supply to the inboard end of the bearing. This practice is required by Lloyds register of shipping. A pressure of approximately 0.35kgf/cm² (5lbf/in²) above outside water pressure at maximum draft is usually considered adequate. Apart from its function as a lubricant, water also acts as a coolant. This important factor contributes greatly to the excellent performance of Tufnol bearings at high speeds and heavy loadings.

On the other hand, a water starved stern tube bearing may generate sufficient heat to damage the laminate. However, tests have shown that failure of the water supply is not likely to damage the shaft even when the heat generated is sufficient to char the bearing. Oils have no detrimental effect on Tufnol laminates and may be used to lubricate bearings which are not suited to water lubrication. It must be remembered however, that oils do not possess the cooling properties of water and should not be used in bearings which generate running temperature in excess of 80°C.

In the case of open-ended water lubricated bearings, the use of greases and heavy oils is not recommended. Grease will clog water grooves, thus restricting the water flow. Grease also tends to trap sand particles, resulting in the formation of an abrasive paste.

Direction of laminae

The expansion of bear brand Tufnol due to water absorption is greatest in the direction normal to the laminate i.e. perpendicular to the plane of the sheet. At first sight, therefore, it might seem better to arrange the staves edgewise to the shaft as shown in figure 13.

This would permit the use of extremely small initial clearances. However, such as arrangement requires a more complex design to prevent the large swelling in the circumferential direction causing dangerously high compressive hoop stresses. Instead, the arrangement shown in figure 14 is recommended, as no precautions need to be taken to limit peripheral stresses except for the usual accuracy in fitting the final stave. However, bearings have been successfully installed with perpendicular laminae and can be supplied if necessary.

Figure 12

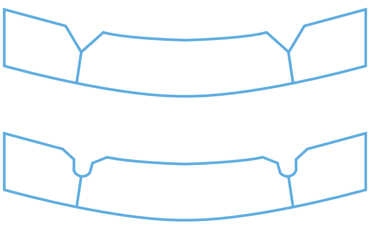


Figure 13

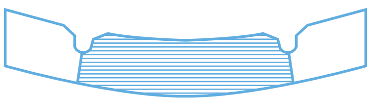
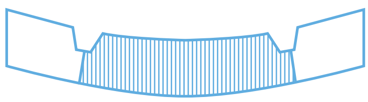


Figure 14



Stave Dimensions

For economic manufacture, staves should ideally be about 75mm to 100mm wide but the exact width needs to be calculated accurately to ensure that the staves will fill the circumferential space between the keys, plus a small allowance for trimming when hand fitting. This is done by calculating the total angle occupied by the keys, subtracting this from 360 degrees and then dividing the remaining angle of arc by a suitable number of staves.

Typical example

A rudder bearing is required to fit into a housing of outside diameter (D) 550mm with a shaft diameter (d) 500mm. There are 2 metal key strips fixed at 180 degrees and the width of each key strip is 50mm. (See Figure 15)

Using the formulae shown in figure 15, the angle subtended by each key is 10°26' so the arc of circumference to be filled by staves is: 360 – (2 x 10°26') = 399°8.
Since the two keys are evenly spaced, an even number of staves will be required. It is found that 20 staves each with a theoretical angle of 16°57' gives a stave width of 81.09mm which is acceptable. To this must be added a small allowance for hand fitting to allow for inaccuracies in the housing and cumulative errors. Adding 0.8mm to each stave, the machined width of stave becomes 81.89mm, which means the actual angle to which the stave will be machined is 17°8.

The bearing clearance after fitting is calculated from the formula;

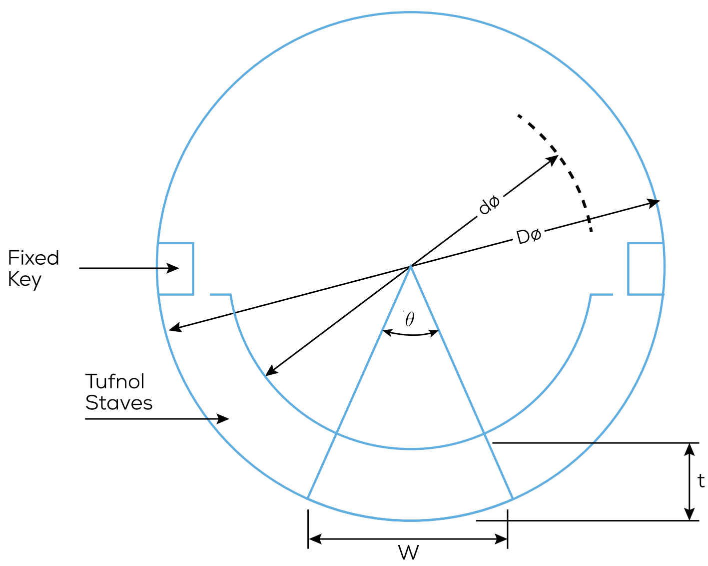
Clearance = (0.025 x D) – (0.0237 x d)

Which in this case gives 1.9mm clearance and swelling allowance. The thickness of material required to produce the staves is 26.85mm plus.

Stave dimensions
Figure 15

$$\frac{W}{D} = Sin(\theta/2)$$

$$t = \frac{D - [d \times Cos(\theta/2)]}{2}$$



Fitting stave bearings

The most common method of fitting Tufnol staves is to place all but one of the staves in a section of the bearing between key strips, holding them in position temporarily by means of wedges in the remaining space. The width of the last stave is then adjusted by removing material to suit the gap.

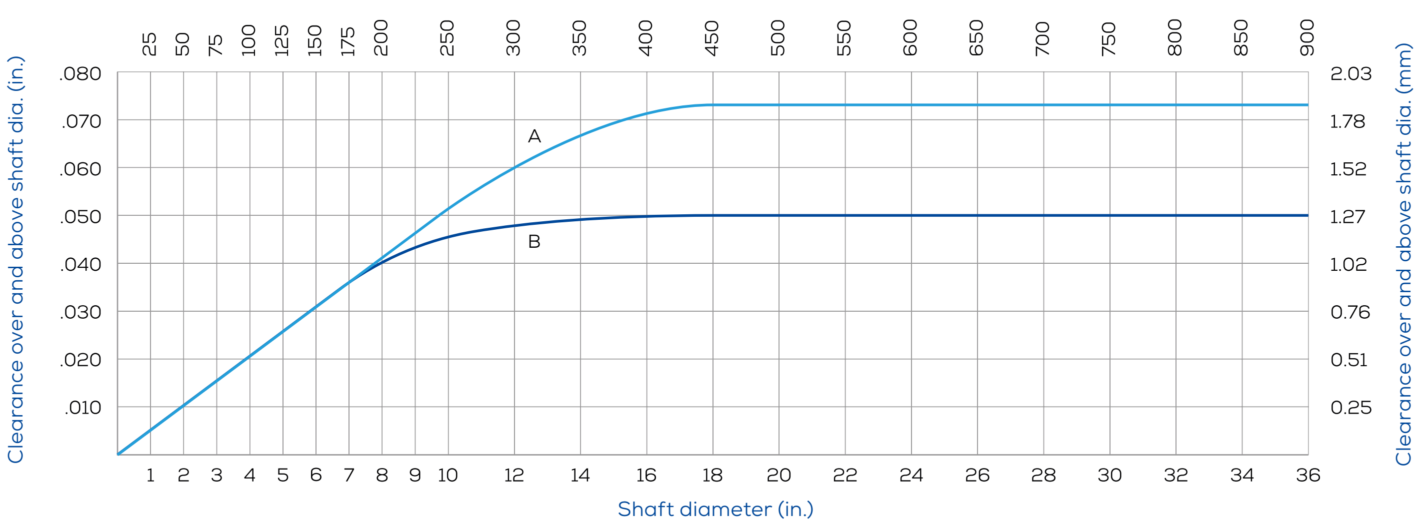
The fit obtained should be such as to allow the final stave to be driven home without undue force. A heavy steel bar, having a short lip or hook at one or both ends is a useful tool for removing any stave which is too tight a fit, thus requiring further slight adjustment on width.

Clearance

With stave bearings fitted in the recommended manner, the initial clearances should not be less than those shown in figure 16. In addition to the appropriate clearance in the bearing bore, it is also advisable to allow an axial clearance of 2.5mm per metre of bearing length.

Figure 16

Clearances for Tufnol Bear brand stave bearings



Curve A. All rudder bearings and stern tube bearings for new buildings and vessels not entering service for a period of approximately 3 months.

Curve B. Stern tube bearings only for vessels returning to service immediately.

Clearances indicated in the graph are based on bearing wall thickness shown in the table. Any machining tolerance should be in addition. Users of bearings having a substantially greater wall thickness are recommended to consult Tufnol.

As a general guide for non-standard wall thicknesses clearance can be found from:

Diametral Clearance = (0.025 x Housing Diameter) – (0.0237 x Shaft Diameter)

Shaft diameter (mm)	Wall thickness (mm)	Shaft diameter (in.)	Wall thickness (in.)
25	3	1	⅛
50	6	2	¼
75	9	3	⅜
100-175	13	4-7	½
200-250	19	8-10	¾
275-375	22	11-15	⅞
400+	25	16+	1

Gear design in Tufnol Laminates

Benefits

Non-metallic pinions machined from fabric reinforced Tufnol laminates are used successfully in many industries to reduce noise and to damp vibration in high-speed machinery and equipment. This application extends from instruments to heavy duty industrial plant.

Long life Tufnol laminated gears are hard wearing. They are also sympathetic to metals with which they work and this results in little or no wear on their mating wheels; often the life of the metal wheels is prolonged by the use of a Tufnol gear in the drive. Tufnol laminates are unaffected by oil, grease or petrol, are generally suitable for use in corrosive atmospheres and can be stored indefinitely without deterioration.

Their mechanical strength, toughness and temperature resistance exceed those of many commonly used thermoplastics materials and enable them to withstand extremely arduous working conditions, as well as the more delicate precision situations. Their resilience provides good resistance to shock loads and their light weight – one sixth of the weight of steel – reduces inertia, which leads to lower power requirements.

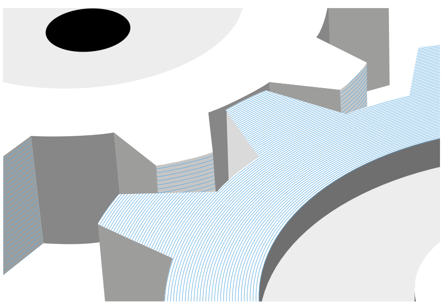
Choice of form and grade

In order to obtain the maximum strength for a Tufnol spur gear, sheet material must be used so that the stress will be taken across the laminae (See Figure 17).

Gears from Tufnol laminates can be made in diameters ranging from a few millimetres up to 1170mm (46in). Sheets can be made, in certain grades, up to 228mm (9in) thick but by riveting together two or more blanks, gears can be made with any width of face. This method can sometimes be more economical for gears less than 228mm (9in) face width. It is usual to machine gears from one of the cotton fabric based Tufnol brands, according to tooth size and form.

As a general guide, Crow and Whale brands are more suitable for coarse-pitched gears in rugged applications. Vole, Lynx and Carp brands and grades 6F/45 are mainly used when fine pitched gears are required. The finest weave materials, Crap brand and grade 6F/45, are especially suitable where an extremely fine finish is required or where the power throughput is slightly above that which the gear formula suggests the material will transmit. Grade 6F/45 is particularly distinguished for its superb, burr-free finish.

Figure 17



Designing Tufnol gears

Tufnol materials are suitable for spur, single helical, double helical, bevel and internal gears.

They may also be used for some forms of spiral gears and racks. They should not, however, be used for worms but can be considered for worm wheels.

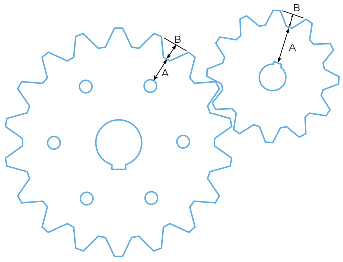
The pinion, or the wheel with the higher speed should normally be made from Tufnol laminates and the mating wheel from metal. The metal gear should preferably be made of hardened steel but, failing this, a machine cut cast iron wheel usually gives good results. It should have machine-cut teeth because non-metallic gears will not mesh truly with a tooth having either a cast or machine-moulded finish. Due to the comparatively low modulus of elasticity, the teeth of a Tufnol gear adapt themselves quickly to suit the profiles of the metal mating gear. Any slight inaccuracies in tooth from and spacing are soon accommodated.

Tufnol to Tufnol drives are not generally recommended as no additional benefits are achieved, except in a few special cases. Such instances may occur, for example, in corrosive conditions or where electrical insulation is required.

The face-width of a Tufnol gear should be a little less than that of the metal mating gear to ensure engagement over the full face width. The depth of material between the root of the tooth and the top of the keyway or rivets should not be less than one and a half times the tooth depth. (See Figure 18)

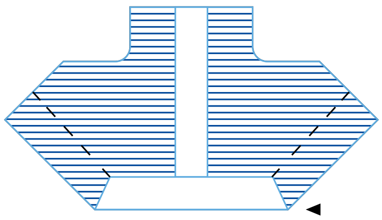
Counterbores and recessed should be omitted wherever possible. They do not contribute significantly to overall weight reduction, and they do not assist in cost saving on material: indeed, unnecessary extra machining may be involved. In some cases, such as certain bevel gears, recesses may cause undue weakening of the section. (See Figure 19)

Figure 18



Min. dimensions at 'A' 1½ times 'B'

Figure 19



De-lamination could occur at this point.
The counterbore should be omitted.

Tooth form

The generally accepted standard 20° pressure angle is normally used and is particularly advisable for gears with a small number of teeth, i.e., 18 or less, to avoid undercutting. This results in weak teeth and leads to interference instead of required line contact on the path of action. For gears with a small number of teeth, it is preferable to increase the addendum and decrease the dedendum. When required, a 14 ½ ° Pressure angle can be utilised, but power capacity is reduced by up to 20%.

Lubrication

It is not essential to lubricate Tufnol gears. Like metal gears, however, their life is improved by the application of a good quality mineral oil. Grease is not generally advisable except possibly in very clean situations, as it is liable to form an abrasive paste with embedded foreign matter.

Power capacity

The following formulae have provided suitable for determining the power transmission capacity for Tufnol gears produced with the standard 20° pressure angle.

Power capacity (S.I. units)

P = .00314 x fw′ x y x V′ x S′ x m
where P = power transmission capacity in KW

fw′ = face width of gear in mm

y = a factor, depending on number of teeth (See Table 9)

V′ = pitch-line velocity in m/s

S′ = safe working stress for TUFNOL gears depending on speed, in MPa

m = module

The safe working stress for static load should be taken as 42 MPa and the values of S′ are derived from the equation

$$S' = 42\left(\frac{0.75}{1+V'} + 0.25\right)$$

Power capacity (Imperial units)

$$hp = \frac{0.000095 \times fw \times y \times V \times S}{dp}$$

where hp = horsepower capacity

fw = face width of gear, in inches

y = a factor, depending on number of teeth (See Table 9)

V = pitch-line velocity, in feet/min (v=0.262 x rpm x pitch dia. In inches)

dp = diametral pitch

S = safe working stress for Tufnol gears, depending on speed, in lbf/in^2

The safe working stress for static load should be taken as 42 MPa and the values of S′ are derived from the equation

$$S = 6000\left(\frac{150}{200+v} + 0.25\right)$$

Designing Tufnol gears

By adopting 42 MPa (6000 lbf/in^2) as the static stress figure, a considerable factor of safety is obtained, particularly for the fine weave grades such as Carp and Lynx brands.

In abnormal stall or excessive overload situations, the laminated gear will usually strip without causing undue damage to the metal gear or other parts of the equipment. There is no general formula for calculating the power capacity of bevel gears produced from Tufnol laminates, as each case requires individual consideration. Our Technical Advisory Service will provide assistance in such cases.

Speeds

In general, Tufnol laminates have greatest power capacity when operated at a pitch line velocity from 600 to 6000 feet per minute (3 to 30 metres per second). Speeds above this may require special consideration but, at very ow speeds, torque or tooth loading should be taken into account in assessing suitability.

Pitch

The list of preferred pitches given in **Table 10** are those which have been found to be most suited for Tufnol gears. These may be varied, however, to suit particular conditions.

Side Plates

Metal side plates or 'shrouds' are occasionally fitted, especially where the face width of the gear is fabricated from more than one piece of sheet. Also, where tapered keyways are used, they can help prevent excessive stress caused by the key being 'overdriven'. In service, sturdy metal side plates can be beneficial for extremely arduous working conditions involving shock loading or severe abrasion.

Table 9

Number of teeth	y
16	0.094
17	0.096
18	0.098
20	0.102
21	0.104
23	0.106
25	0.108
27	0.111
30	0.114
34	0.118
38	0.122
43	0.126
50	0.130
60	0.134
75	0.138
100	0.142
150	0.146
300	0.150
Rack	0.154

Table 10

Pitch		Power Capacity	
module	dp	kW	hp
2.5		0.2	
	10		0.25
3		0.7	
	8		1
4		2	
	6		3
5		4	
	5		5
6		6	
	4		9
8		11	
	3		16
10		18	
	2.5		25
12		40	
	2		60
16		100	
	1.5		150

Keying

This is the preferred method of fixing a Tufnol gear to the shaft and in the majority of cases, a keyway cut into a plain bore is adequate. Parallel keys are strongly recommended. Tapered keys, if used, may possibly be overdriven and it is advisable to fit steel shrouds or bushes to take the wedging action of the key. Bushes, shrouds, or plates should also be used to reinforce the keyway when the maximum keyway stress will be exceeded. Grub screw fixing is not usually recommended unless a metal bush, or collar is fitted to take the screw. Force fitted, knurled or splined shafts require careful design but can be very successful in the right situation.

For plain gears the keyway stress should not exceed 21 Mpa (3000 lbf/in2). This stress may be calculated from the following equations:

Keyway stress (S.I. units)

$$S' = \frac{1000\,P'}{L' \times H' \times V'}$$

Where S' = stress on keys, in MPa

P' = power transmitted, in Kw

L' = length of keyway, in mm

H' = height of keyway, in mm

V' = peripheral speed of shaft, in m/s

Keyway stress (Imperial units)

$$S = \frac{33000}{L \times H \times V}$$

Where S = stress on keyway, in lbf/in^2

P = power transmitted in horsepower

L = length of keyway, in inches

H = height of keyway, in inches

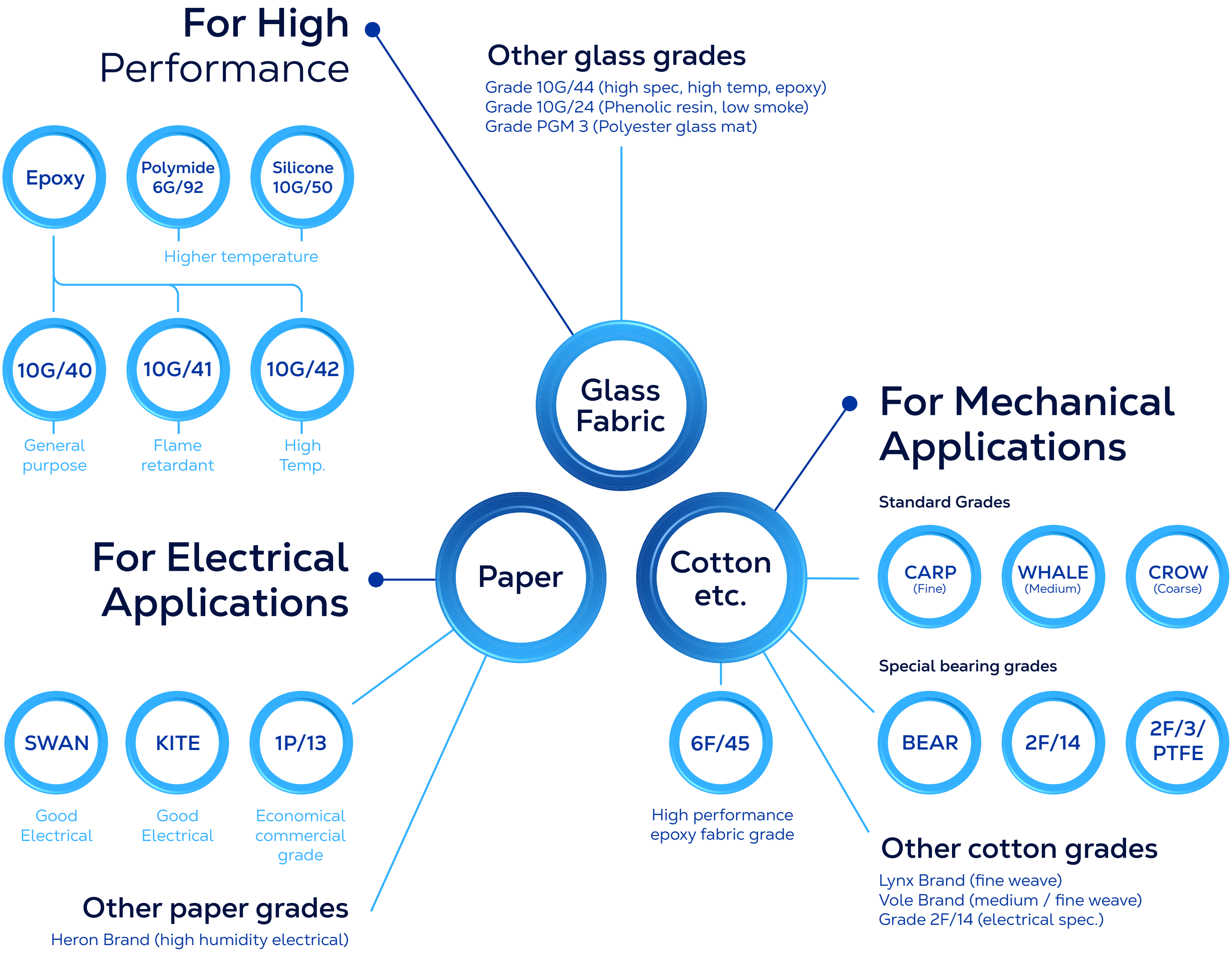
V = peripheral speed of shaft, in ft/min

The equations relate only to the stress caused by transmitting the working torque. Stressed due to high interference fits in the keyway should be kept to an absolute minimum but, if a particularly high interference must be accommodated, the use of steel shrouds should be considered.

Installation and Maintenance

Gears produced from Tufnol laminates will give a long and trouble-free life, provided certain points are borne in mind when fitting. The shafts should be checked for alignment and any play or wear in the bearings taken up. Shaft centre distances should be checked to give correct clearance and backlash. Care should also be taken to ensure that there is a minimum of end-play on the shafts, which might otherwise prevent correct engagement. The pinion should be a good fit on the shaft and the key must engage the keyway for its entire length. The mating gear must run true, and the teeth of the existing gears should be examined for signs of wear, incorrect tooth shape or general damage.

Tufnol's product overview



TUFNOL

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