

The invention relates to a bush for a heavily loaded pivot or bearing working in an abrasive environment, according to the first part of Claim 1. Such a bush or bearing is known from the document DE-A-25 45 922.

In various engineering sectors, a need exists for pivots or bearings which are not demanding as regards rotation speed or precision, but which are robust and capable, notably, of offering:

- a) good resistance to wear, notably to abrasive wear (for example in the presence of sludges or iron oxides);
- b) a good loading capacity, withstanding dynamic loading and shocks;
- c) good friction characteristics (quiet operation, greasing only at the time of assembly);
- d) good corrosion resistance, for withstanding the presence of water or salt spray.

The following can, for example, be cited:

In the field of civil engineering, pivots for mechanical shovels, loaders, bearings for elevators, pivots for small ends of piston pumps;

In the iron and steel sector, pivots for drag chains, mould closures, bearings for hearth-furnace wheels;

In the agricultural machinery sector, machine bearings, pivots for tractor front axles;

In the transport vehicle sector, pivots for suspension springs

and brake linkages.

Conventional bearings, such as ball or roller bearings, designed for high rotation speeds, are too expensive for uses of the types just listed, since the expected loadings would make it necessary to oversize them, and they would need to be housed in sealed housings, in order to withstand without damage the risks of abrasion and corrosion, which would increase their cost.

Bearings with relatively soft metal linings, such as bronze and white metal, do not withstand abrasive environments well, or high loading pressures.

Surface-hardened steels provide a more satisfactory solution for the production of bearings of the type considered above, particularly when the surface treatment improves corrosion resistance and the coefficient of friction. However, surface treatment, especially when it is limited to the bearing surface, is relatively costly. And performance under load remains inferior to what would be desirable.

The invention brings a remarkable solution to the field in question. It proposes for this purpose a bush for a heavily loaded pivot or bearing working in an abrasive environment, having a body, annular overall with an axial bore provided with a lining in which a shaft pivots in contact with a bearing face of the lining, this lining consisting of a rectangular strip of appropriate thickness, wound around an axis perpendicular to its length and hooped in the bore, made of steel of which at least the bearing face has received a surface hardening treatment, characterised in that the bearing face is hardened to a relative depth, related to the thickness, of between 0.23 and 0.27, this strip having, with respect to the evolute of a neutral fibre of an unstressed lining in the bore, a relative excess length of between 0.3 and 9×10^{-2} .

The Applicant discovered that surface hardening, over a limited depth so as not to make the core of the strip fragile, combined with a measured hooping of the lining sufficient for the bearing face to be compressed tangentially to its surface, provided the bush with particularly high resistance to abrasive wear and, in a general fashion, conferred upon it unexpected friction properties. The detailed description will underline these properties.

Preferably, the range of relative excess length, expressed in terms of 10^2 , is defined, as a function of the diameter ϕ of the bore, in accordance with the following table:

ϕ bore (mm)	Relative excess $\times 10^2$
10-25	3-9
25-35	2.2-4.3
35-45	2-3
45-55	1.7-2.9
55-100	1.1-2.3
100-140	0.7-1.5
140-260	0.4-1.0
260 and above	0.3-0.7

It will be noted that the appropriate relative excess length decreases as the diameter of the bore increases. Higher levels of plastic deformation therefore correspond to high relative thicknesses of the lining. In practice, strips with a thickness of between 1.5 and 5.0 mm will be used, without exceeding 15% of the diameter of the bore.

Preferably, the surface treatment is a thermochemical treatment which gives rise to a diffusion of a heteroelement in the relative depth. This heteroelement can be nitrogen supplied by nitriding in a salt bath and by gaseous nitriding, carbon supplied by carburizing, in which case the strip will be quench hardened, or carbon and nitrogen simultaneously, by carbonitriding. Finally, the heteroelement can be chromium

(chromizing).

Good results are also obtained either through a quench hardening of the bearing face after surface heating by means of high-frequency induction, or by a surface work-hardening of this bearing face by means of rolling, hammering, burnishing, shot peening or knurling.

Secondary characteristics and the advantages of the invention will, moreover, emerge from the description that follows, by way of example, with reference to the accompanying drawings in which:

Figure 1 is a view, partially cut away, of a bearing bush according to the invention, engaged on a shaft;

Figure 2 is a partial diagrammatic cross section of a bush before the lining is engaged in the body of the bush.

According to the embodiment chosen and depicted in the figures, the bush 1, overall, in which a shaft 2 pivots, has an annular body 3, in which there is a cylindrical bore of diameter D_3 . In this bore, a lining 4 is fitted by force, formed by a rectangular steel strip which has been wound to form a cylinder around an axis perpendicular to its length, of thickness e .

The internal face $4b$ of the lining, which forms a bearing face for the shaft 2, has been surface hardened over a depth of between 0.23 and $0.27e$; the surface hardening process will be commented upon below.

It will, however, be noted that the two faces, internal and external, of the lining 4 can have received a surface hardening treatment, for reasons of convenience, it being understood that any hardening of the external face has no functional role.

The winding of the rectangular strip forming the lining 4 about an axis perpendicular to its long sides causes the two short sides of the rectangle to coincide, in the form of a slot 5 parallel to the axis.

As depicted in Figure 2, the external diameter D4 of the lining 4 is greater, before fitting, than that of the bore D3, so as to obtain, after fitting, a hooping which, in the bearing face 4b, causes tangential compression stresses between limits, of which the Applicant discovered the existence and calculated the values.

The following example will enable the reasoning of the Applicant in the characterisation of the invention to be understood.

EXAMPLE 1

A rocker bearing is to be produced for a case-hardened 16NC6 steel shaft, quench hardened and precision ground to a diameter of 30 mm.

The body of the bush is annular, with an internal bore with a diameter D₃ of 34 mm.

For the lining, a 2 mm thick strip of non-alloyed XC38 steel is first used, which is cut out to form strips 100 mm wide.

From these strips, rectangles of length L are drawn, derived from the evolute L₀ of the unstressed neutral lining fibre.

Here,

$$L_0 = (D_3 - e) \times \pi \quad (1)$$

so that, in this case, L₀ = 100.53 mm

$$\text{The length } L = (1 + \lambda) L_0 \quad (2)$$

is taken as an increasing value between 103 and 104 mm (λ being between 2.46 and 3.45%).

It will be noted that two tests, with $L = 102$ and $L = 105$, proved inoperable. With $L = 102$, the lining was driven by the shaft; with $L = 105$, the deformation of the lining when being fitted is such that it is impossible to insert the shaft into the bush.

The rectangles were nitrided in a cyanate salt and alkali carbonate bath according to FR-A-2 171 993 and FR-A-2 271 307, the depth of the nitrided layer being substantially 0.5 mm, or 0.25 times the thickness, substantially, the depth regulation being adjusted by the immersion time.

The rocker bearings were subjected to wear tests in alternate rotation over 100° of arc, at a frequency of 0.67 Hz, with cycles of 15 seconds on, 60 seconds off.

Contact pressure 40 MPa.

Mean peripheral speed 0.035 m/s.

Iron sinter environment.

Greasing at time of assembly - no lubricant provided during test.

Duration of test 200 hours.

At the end of the test, the wear on the bearing face 4b is measured; the results are reported in Table I below:

TABLE I

L(mm)	103	103.4	103.45	103.5	103.6	103.65	103.7	104
$\lambda \times 10^2$	2.46	2.85	2.90	2.95	3.05	3.10	3.15	3.45
wear (mm)	0.9	0.55	0.10	0.09	0.08	0.11	0.6	0.8

It can be seen that there is a minimum level of wear for $\lambda \# 3 \times 10^{-2}$.

It should, moreover, be noted that the semi-empirical determinations of the hooping levels of thin tubes for a tight fitting would have led to the adoption of a length L of 103.7; it was verified that the optimal hooping level for the present

invention was, in a constant fashion, slightly below the hooping levels recommended for a tight fitting.

Tests were then conducted in order to determine the optimum depth of surface hardening.

EXAMPLE 2

Starting from Example 1, a series of tests were conducted with $L = 103.6$ ($\lambda = 3.05 \times 10^{-2}$), varying the depth of nitrogen diffusion through the time of immersion of components in the salt bath.

The results are reported in Table II, which follows:

TABLE II

relative
depth

p/e	0.4	0.333	0.286	0.25	0.222	0.2	0.182	0.167
wear (mm)	-	0.8	0.3	0.08	0.35	1	1.5	2.6

For a depth of 0.4, the lining was practically hardened to the core, and broke within the first few minutes of the test.

The Applicant then, in the light of the tests conducted, and bringing these tests together with what is known to experts concerning rules for the tight fitting of thin hooped rings, established ranges of relative excess length for the strips with respect to the evolute of the neutral fibre of an unstressed lining as a function of the bore diameters. It should be noted that the bore with the smallest diameter measured 10 mm, with a strip 1.5 mm thick, and that, however great the bore diameter, it is pointless to exceed a thickness of 4 to 5 millimetres for the strip.

Table III indicates the ranges of relative excess lengths λ as

a function of the diameter ϕ .

TABLE III

ϕ bore (mm)	Relative excess $\lambda \times 10^{-2}$
10-25	3-9
25-35	2.2-4.3
35-45	2-3
45-55	1.7-2.9
55-100	1.1-2.3
100-140	0.7-1.5
140-260	0.4-1
260 and above	0.3-0.7

EXAMPLE 3

The rate of wear in a pivot as defined in Example 1 was compared with that of pivots treated according to prior methods. Table IV presents these comparisons.

TABLE IV

Nature of bush	wear (mm)
Example 1	0.09
Low temperature electrochemical sulphuration (FR-A-2 115 505)	0.45
Hexagonal lamellar layer (FR-A-2 428 682)	0.35
Hard chrome steel	seizing
Steel covered with Cr_2O_3 ceramic	flaking
Steel loaded with molybdenum	2
Steel loaded with stellite	2

EXAMPLE 4

The wear on a pivot according to Example 1 was compared with a nitrided solid X38 steel pivot. The results for 5 samples were as follows:

	wear (mm)
Bush according to Example 1	0.08 - 0.10
Solid bush	0.2 - 0.25

EXAMPLE 5

The nature of the thermochemical diffusion treatment was varied, all other conditions remaining the same..

TABLE V

	wear (mm)
Thermochemical diffusion treatment	
Nitriding in salt baths	0.09
Gaseous nitriding	0.15
Carbonitriding	0.12
Case hardening	0.10
Chromizing	0.18

It can be seen that, though some treatments are more efficacious than others, the results are, in all cases, better than those for conventional pivots.

EXAMPLE APPLICATIONS

6. On mechanical shovels

The invention was applied to the pivots on the bucket arm - which work in oscillation at low speed (0.01 to 0.05 m/s), with a contact pressure of 120 MPa, at ambient temperature and in a mildly abrasive environment, at the rate of 8 hrs per day, with periodic lubrication.

The shaft is made of steel quench hardened at high frequency, the normal bush from solid case-hardened steel. The service life is as high as 600 hrs but seizing is sometimes observed after 50 hours.

The lining of the bush according to the invention was case-hardened and quench hardened. The service life increased to over 1000 hours, without degradation of the surfaces.

7. Bearing for moving-hearth furnace wheel

The rotation speed is 10 rpm ($V_g = 0.1$ m/s), the contact pressure 10 MPa, the temperature $200^\circ - 300^\circ\text{C}$, the operating frequency 5 mins every two hours. The environment is abrasive and greasing is periodic.

The shaft is made of hardened steel; the original bearing is a roller bearing - the service life was six months.

The lining of the bushes of the invention was nitrided in a salt bath. These bushes have been in service for over a year, without visible degradation.

8. End pivot of a drill ram

This pivot works in oscillation at very low speed ($V_g = 0.05$ m/s).

The pressure exceeds 100 MPa, the operating temperature is between -10° and $+40^\circ\text{C}$; the duration of operation is 16 hours per day in an abrasive environment. There is periodic greasing.

The shaft is made of hard chrome steel. The original bush was made of solid 100C6 steel (bearing steel). Seizing appeared after a few weeks.

According to the invention, the lining is made of case-hardened steel. In over 12 months, no seizing was observed.

9. Small-end pivot of a piston pump for hydraulics

The operating conditions are: an oscillation ($V_g = 0.3 \text{ m/s}$), a contact pressure of 15 MPa, a temperature of 60°C , a frequency of 8 hrs per day, an environment of hydraulic oil and lubrication by oil splash.

The shaft is made of nitrided steel; the original bush was made of fine-grained iron. The service life was 75 hours (seizing).

According to the invention, the lining of the bush is made of carbo-nitrided steel. The service life exceeds 2000 hours.

Examples 4, 6 and 8, in conjunction with Table I, show that tangential compressional stresses in the bearing face, within a limited range, unexpectedly have decisive effects on the friction qualities of the bushes. Furthermore, the existence and values of these tangential compression stresses are not obvious, even for an expert. Even if the "in situ" experimentation had not been confidential, this experimentation would not have constituted a disclosure.

Furthermore, in parallel with experimentation in which the surface hardening treatment is a thermochemical treatment with a heteroelement diffused in the surface layers, the Applicant has conducted experiments concerning other types of surface hardening.

Bushes were produced with the same dimensions as in Example 1. After winding, the bearing faces of the linings were hardened by means of quench hardening preceded by heating to a slight depth by means of high-frequency induction with an inductor inserted into the inner recess of the lining. Wear tests, conducted under the same conditions as in the examples, showed wear of around 0.20 - 0.23 mm. Although these results appear to be less good than those in which the linings received thermochemical treatments, they remain good compared to those of the corresponding conventional bearings. Furthermore, for

very large runs without a change of inductor, the cost of treatment is very low, and production rates can be high.

The Applicant also conducted experiments in which the bearing surface of the linings was hardened by surface work-hardening.

In a known fashion, the surface work-hardening can be produced by means of:

- Roller burnishing (or rolling), in which plastic deformation is brought about by the rolling of rollers or balls on the bearing surface, before tubular shaping, owing to the limited contact surface.

- Hammering, in which the work-hardening is produced by means of impacts from a hard hammer, generally moved by compressed air.

- Burnishing, in which a hard tool rubs the bearing surface at high pressure.

- Prestressed shot blasting, known as "shot peening", frequently recommended for improving resistance to fatigue and stress corrosion, which consists of projecting glass, steel or ceramic balls at high speed.

- Knurling, which, in addition to work hardening, impresses, by means of surface forging, profiles able to serve as lubricant storage.

This surface work hardening leads, in addition to a hardening with residual compression prestressing, to a local modification of the crystalline structure of the metal, which can go as far as an amorphous structure, which reduces the risks of seizing.

The steels most suitable for work hardening are carbon-based

steels (XC 10 type), austenitic stainless steels (Z 3 CN 18-10 type), and especially manganese steels (Z 120 M 12 or Z 120 M 13 type).

Experiments have been conducted, under the conditions of Example 1, on a 2 mm thick Z 120 M 12 steel, knurled with grooves around 0.3 - 0.4 mm deep, creating a hardening over a depth reaching approximately 0.4 - 0.5 mm. After 200 hours of operation as in the various examples, the wear did not exceed 0.1 mm, comparable to that of the best tests with thermochemical treatment.

Of course, the invention is not limited to the examples described, but embraces all variant embodiments within the scope of the claims.

CLAIMS

1. Bush (1) for a heavily loaded pivot or bearing working in an abrasive environment, having a body (3), annular overall with an axial bore (D3) provided with a lining (4) in which a shaft (2) pivots in contact with a bearing face (4b) of the lining, this lining consisting of a rectangular strip of appropriate thickness (e), wound around an axis perpendicular to its length and hooped in the bore (D3), made of steel of which at least the bearing face has received a surface hardening treatment, characterised in that the bearing face is hardened to a relative depth, related to the thickness (e), of between 0.23 and 0.27, this strip having, with respect to the evolute of a neutral fibre of an unstressed lining in the bore, a relative excess length of between 0.3 and 9×10^{-2} .

2. Bush according to Claim 1, characterised in that the range of relative excess length, expressed in terms of 10^{-2} , is defined, as a function of the diameter ϕ (D3) of the bore, in accordance with the following table:

ϕ bore (mm)	Relative excess $\times 10^{-2}$
10-25	3-9
25-35	2.2-4.3
35-45	2-3
45-55	1.7-2.9
55-100	1.1-2.3
100-140	0.7-1.5
140-260	0.4-1.0
260 and above	0.3-0.7

3. Bush according to one of Claims 1 and 2, characterised in that the strip thickness (e) is between 1.5 and 5.0 mm, without exceeding 15% of the diameter of the bore (D3).

4. Bush according to one of Claims 1 to 3, characterised in that the surface hardening treatment is a thermochemical



treatment causing a heteroelement to be diffused in the said relative depth.

5. Bush according to Claim 4, characterised in that the heteroelement is nitrogen.

6. Bush according to Claim 5, characterised in that the thermochemical treatment is nitriding in a molten bath of cyanates and alkaline carbonates.

7. Bush according to Claim 4, characterised in that the heteroelement is carbon introduced by carburizing, the strip then being quench hardened.

8. Bush according to Claim 4, characterised in that the thermochemical treatment is carbonitriding.

9. Bush according to Claim 4, characterised in that the heteroelement is chromium diffused by means of chromizing.

10. Bush according to any one of Claims 1 to 3, characterised in that the surface hardening treatment is a quench hardening after surface heating of the bearing face by means of high-frequency induction.

11. Bush according to any one of Claims 1 to 3, characterised in that the surface hardening treatment is a work-hardening of the bearing face obtained by means of a process chosen from amongst rolling, hammering, burnishing, shot peening and knurling.

