Improved surface finish

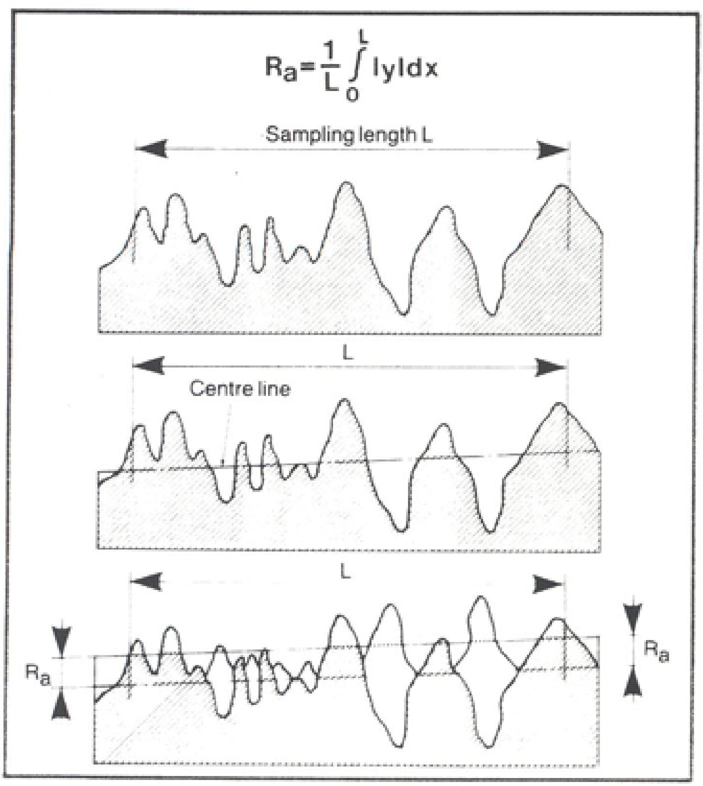
In this chapter, we shall explain some common terms and concepts used in the assessment of surface finish (also commonly referred to as surface roughness or surface texture). We shall also give examples of what the improved surface obtained from roller burnishing means in terms of the performance of the workpiece in service.

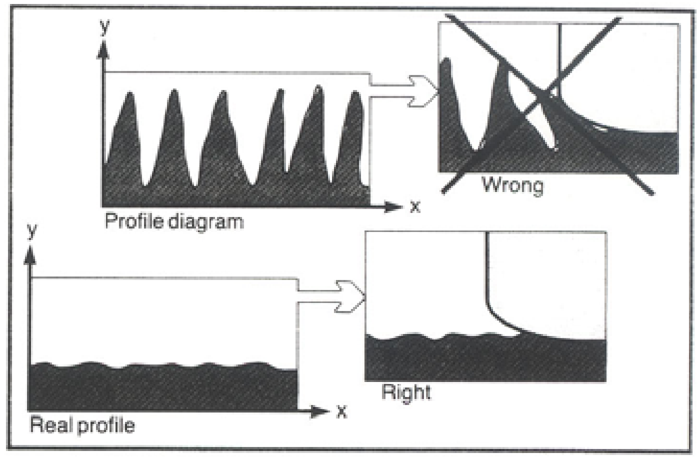
Surface finish criteria

In assessing surface texture, the deviations of the real surface from the ideal surface are measured. The profile that is obtained from measurement of the real surface is represented graphically in a profile chart. Normally, the y axis is plotted on a scale ten times larger than the x axis. There is therefore a widespread misconception that the peaks of the surface are bent down during roller burnishing. In actuality, however, the surface profile is flatter than shown in the diagram and the material in the peaks is displaced to the valleys.

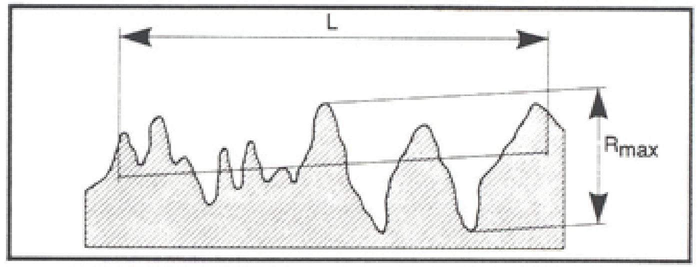
The R_a value (=CLA, Centre Line Average) is normally used to specify surface roughness. The R_a value cannot be read directly from a profile curve, but is instead obtained with the aid of modern integrating stylus instruments.

The R_a value is obtained in the following manner: A centre line is drawn over a sampling length L (see figure). The centre line is located so that the sum of materialfilled areas above the line is equal to the sum of non material-filled areas below the line. The curve is then folded so that the profile is above the centre line. A new centre line is plotted in the new profile curve in the same manner as before. The R_a value is the distance between the two lines.

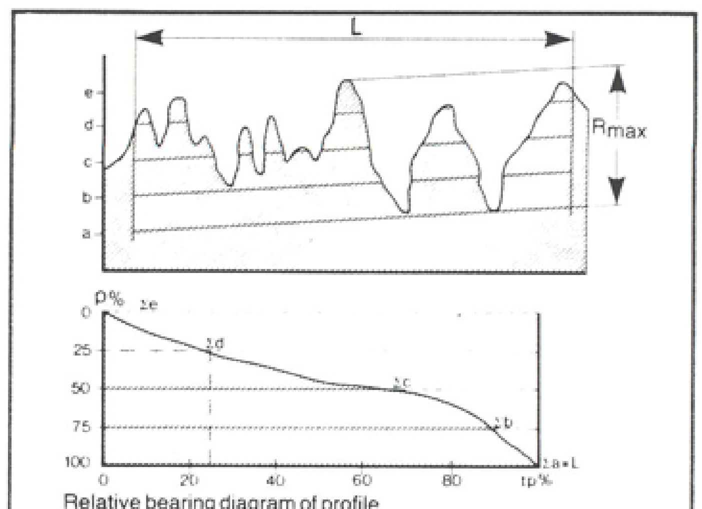




The maximum value R_{max} (R_t) of the surface deviations is another criterion that is often used in surface texture assessment. R_{max} is the difference between the highest peak and the lowest valley in the profile graph.



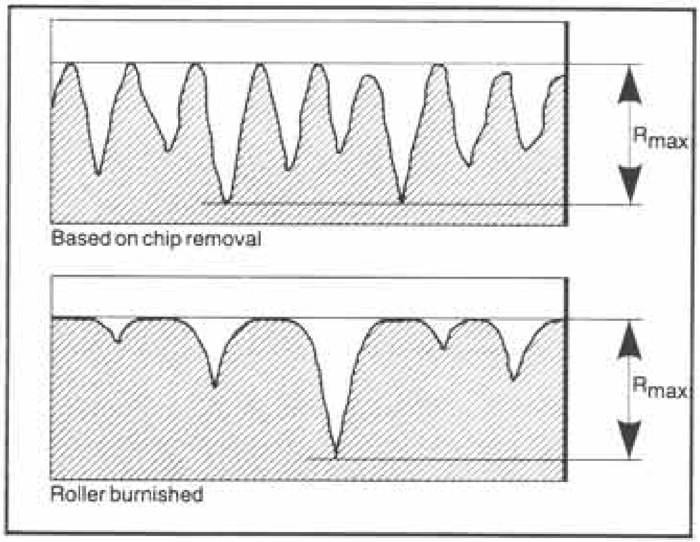
Extreme peaks result in poor bearing capacity and are worn down very quickly upon contact with another surface. In order to describe the abrasion resistance of the surface, the bearing area at different levels of the surface profile is given. The levels are counted from the highest peak and are expressed as percentages of R_{max}. The bearing area of the different levels can be plotted in a bearing capacity graph.



Example: The bearing capacity tp at the bearing capacity level p = 25% of R_{max} is expressed as follows (see figure):

$$t_p = \frac{\Sigma d}{L} \approx 25\%$$

The R_a and R_{max} values say nothing about the properties of the surface as far as bearing capacity and abrasion resistance are concerned. The figure below shows a comparison of the profile of a surface that has been machined by means of a chip-removing method and a surface that has been roller burnished. The rough-machined surface before roller burnishing had gouges in it. As a result, both surface have the same R_{max} value. But when the structure of the surfaces is studied, it is found that the roller burnished surface has much higher bearing capacity and abrasion resistance, while the peaks on the surface machined by means of the chip-removing method will quickly be worn away. In assessing surface texture the best way is to measure both the R_a-value and the bearing capacity.

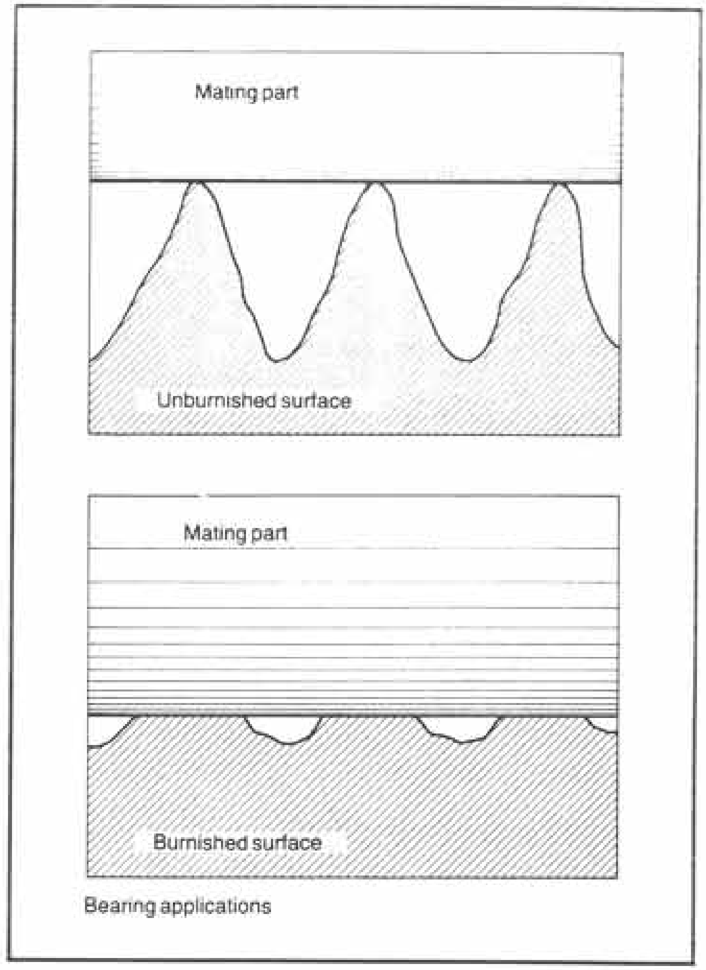


Importance of surface character

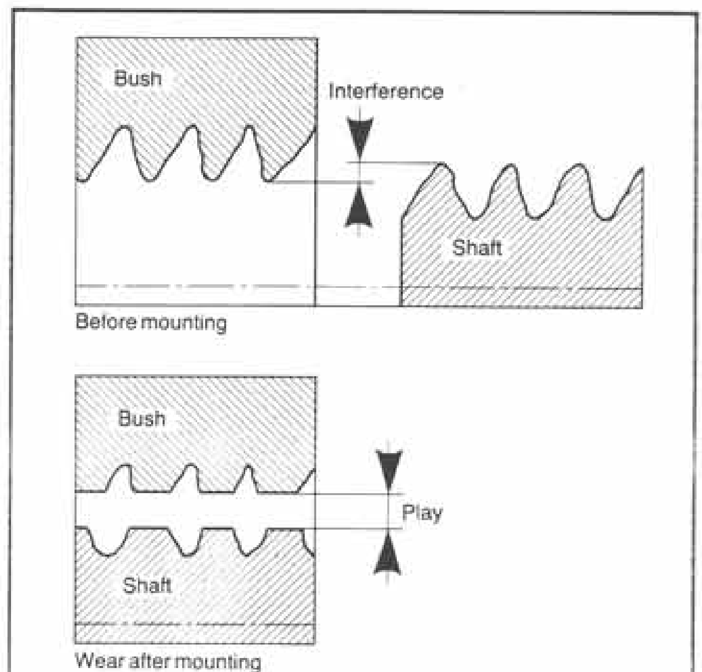
The required surface finish is dependent on what the part is to be used for. We have already established that roller burnishing improves the surface finish by levelling out the peaks on the surface profile. This results in a higher bearing capacity, i.e. the contact area between the workpiece and its mating surface increases.

In bearing applications, the peaks on an unburnished surface are rapidly worn down by the opposing bearing surface. This results in increased running clearances, which can lead to bearing failure. If the surface is roller burnished, the load will be distributed over a larger area. Bearing life will therefore be extended due to the higher abrasion resistance of the bearing surface.

A certain surface finish is obtained in the machining of mating surfaces, for example in an axle-hub joint. Measurement and tolerance classification take place on the peaks of the surface profile. During and after assembly, however, plasticizing of the peaks takes place, as a result of which the effective axle diameter is smaller than the measured diameter, at the same time as which the effective hub diameter is slightly larger than the measured one. The consequence is a loose fit. Roller burnishing increases the life of the fit by providing a larger contact area between the surfaces from the start.



In certain applications, for example pistons, valve bodies, cylinders and parts with similar functions, continuous lubrication is necessary. In roller burnishing, it is possible to



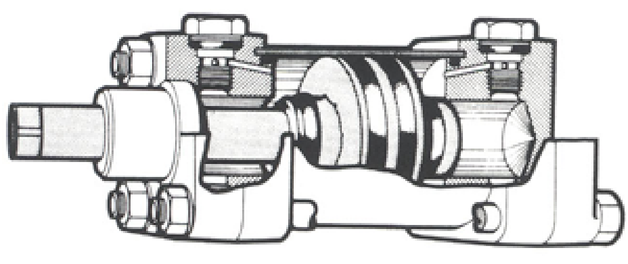
leave pockets (valleys) in the surface by controlling rolling forces, tool size and hole size. These pockets then act as oil reservoirs, extending the life of the part.

Noise is a common problem that is often costly to deal with. Moving parts that abrade against one another normally generate high sound levels. Smooth surfaces with a larger bearing capacity reduce such abrasion and thereby the sound level. The electric motor industry, for example, has derived great benefits from noise reduction through the roller burnishing of moving parts.

Friction between moving contact surfaces leads to heat generation. Temperature rises cause dimensional changes that can have an adverse effect on the function of the parts. Friction, however, is directly related to surface finish. By roller burnishing, it is possible to obtain Ra values that can reduce friction by up to 35%.

Example – life of hydraulic cylinders

Seal wear is of great importance for the life of hydraulic cylinders. The factor that has the greatest effect on cylinder life is wear of the sealing surfaces in the cylinder tube and on the piston rod.

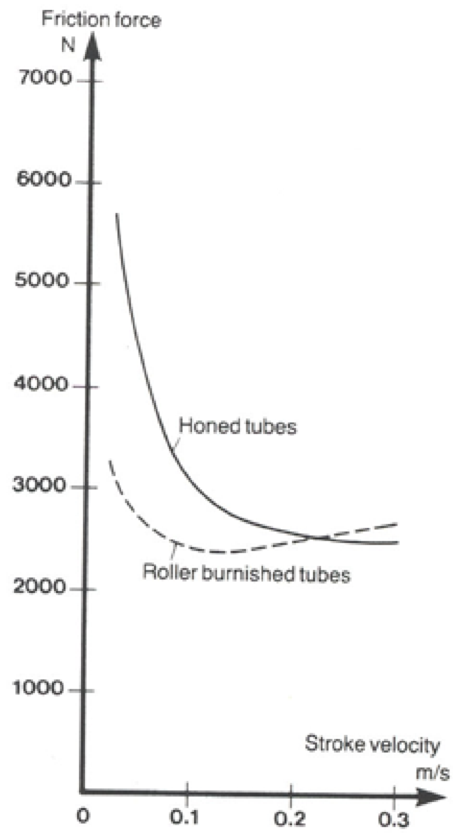


Double-acting hydraulic cylinder

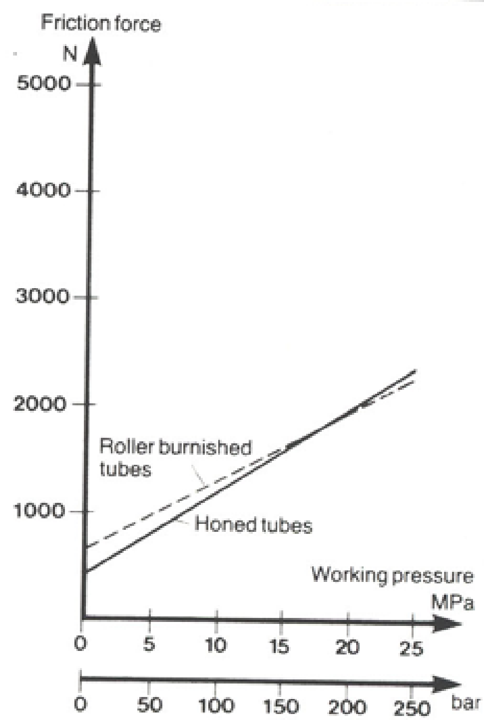
In order to shed further light on the importance of surface texture and surface character, we shall study how different tube surfaces influence piston seal wear in hydraulic cylinders. One study has compared seal wear, friction and stickslip effect in hydraulic cylinders where the tube surfaces have been finished by honing as compared with roller burnishing.

The same type of piston seal – designed as a compact seal with double-acting function – was used in the study.

When different tube surfaces are compared, it is found that the force of friction is lower for roller-burnished tubes than for honed tubes. At high working pressure and high stroke velocities, the force of friction increases for roller burnished tubes. But it is at low stroke velocities that high friction can cause problems through the stick-slip effect, leading to a jerky motion. In the graph, we see that starting friction is almost twice as high for honed tubes that have been roller burnished.



Force of friction as a function of stroke velocity for different tube surfaces at working pressure 25 MPa (250 bar).

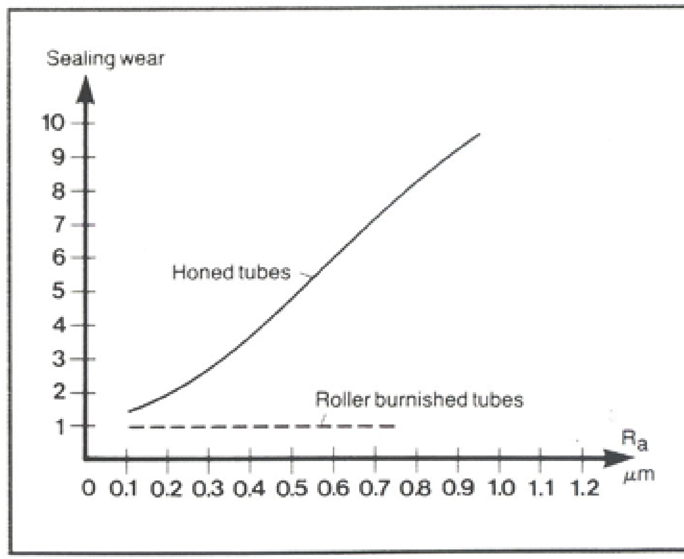


Force of friction as a function of working pressure for different tube surfaces at stroke velocity 0.16 m/s.

No correlation has been found between the force of friction and the surface finish. Rather, the difference depends on the differing character of the surface finish on the tubes Honing produces a surface characterized by regular grinding scratches. A roller burnished surface has a bright appearance without scratches or craters.

Seal wear was found to be highly dependent on the surface texture and character of the tube surface. Surface character is, as we have already seen, dependent upon the manufacturing method used, while surface finish can vary for each manufacturing method. Seal wear as a function of surface finish is plotted in the graph to the right.

In the case of honed surfaces, wear is highly dependent on the surface finish. The R_a value should be 0.4 μm or smaller. Roller burnished tube surfaces cause very little seal wear, which is, moreover, independent of the surface finish within the tested range, R_a 0.08 – 0.8 μm.

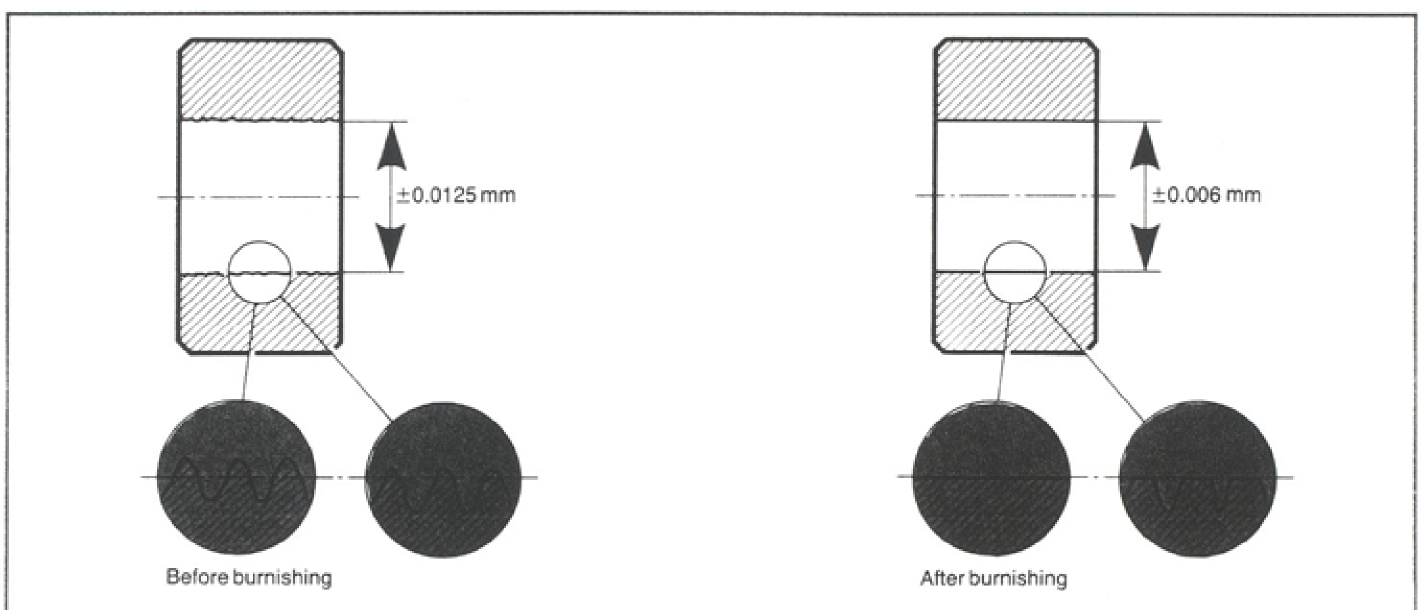


Seal wear after 100 000 cycles has a function of surface finish for different tube surfaces at a working pressure of 25 MPa (250 bar) and a stroke velocity of 0.16 m/s.

Accurate sizing

When high dimensional accuracy is required, Sandvik Coromant roller burnishing tools can be used for sizing. The tools feature a built-in micrometer by means of which the size of the part can be changed as little as 0.0025 mm in one pass. Sizing with roller burnishing tools is influenced by the ductility of the material, the tolerance before burnishing and the profile of the premachined surface. In general, however, roller burnishing gives a 25% closer tolerance in steel and a 50% improvement in tolerance in high ductility materials, while the tolerance in low ductility materials such as cast iron is only improved by about 20%.

Assume that deviations of ±0.0125 mm on the hole diameter are obtained in the manufacture of bushings. Closer tolerances can be met by roller burnishing the bushings. If the bushings are made of high ductility material and have a favourable surface profile, the tolerance after roller burnishing may be improved to ±0.006 mm. Surface finish can vary between the different bushings, however. The bore diameter of certain bushings may be so close to the nominal dimension that the peaks are merely flattened down a bit, while on others, the material must be redistributed to a considerably greater extent in order for a dimensional accuracy of ±0.006 mm to be obtained.

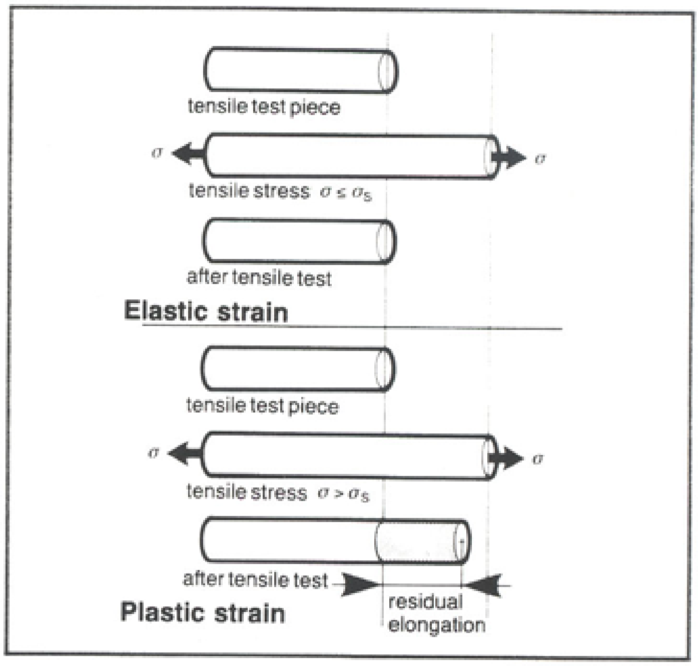


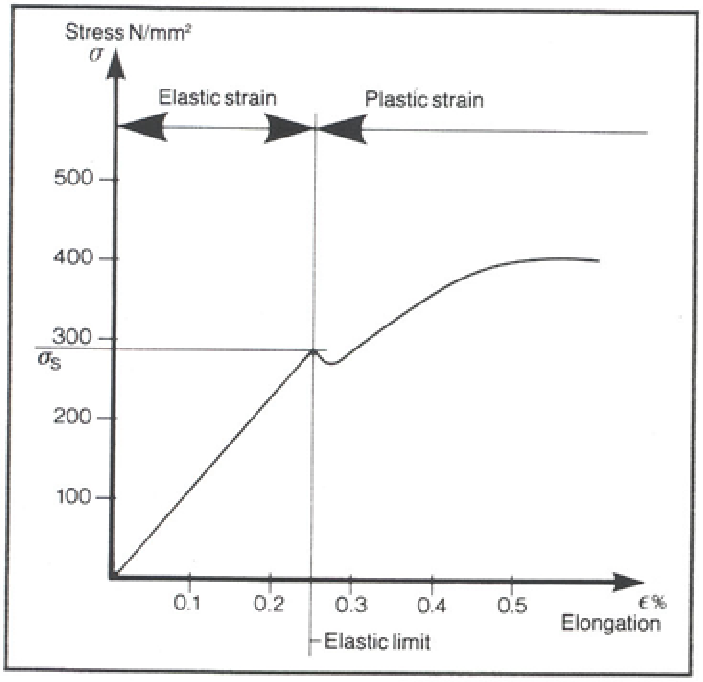
Improved metallurgical properties

Besides improving surface finish and dimensional accuracy, roller burnishing alters the properties of the material. These alterations consist of improved metallurgical properties and afford advantages such as increased hardness, corrosion resistance and resistance to fatigue failure.

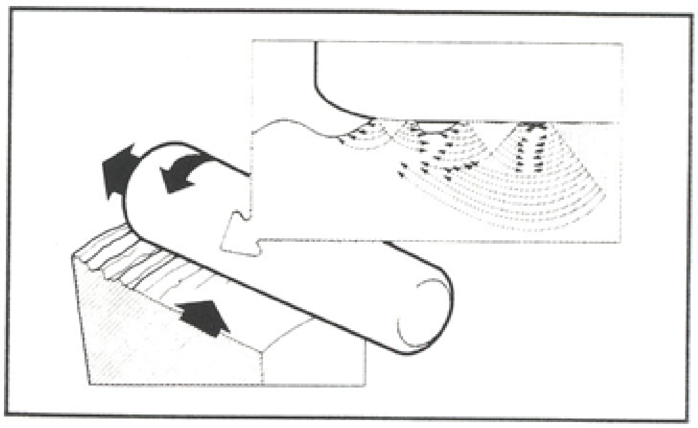
Plastic deformation

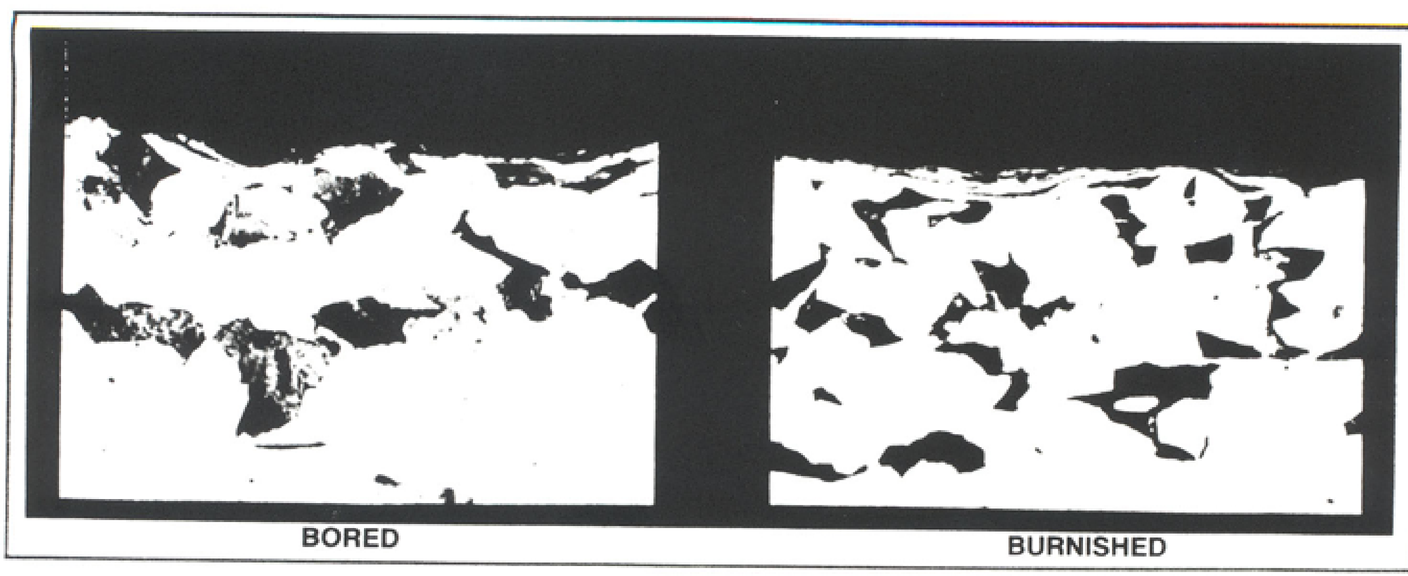
Roller burnishing causes a plastic deformation of the material. As we all know, all material is composed of atoms. The bonds between the atoms are slightly elastic and permit some movement of the atoms. In the case of elastic deformation, the atomic lattice in only sligtly deformed and the atoms resume their original positions when the external load is relieved. In roller burnishing, the material is loaded beyond its elastic limit σ_S. A plastic flow or plastic deformation of the material is said to take place. This plastic deformation persists even after the load is removed.





At a given depth below the surface, the material is elastically deformed and tries to spring back. This gives rise to compressive stresses at the surface and tensile stresses in the elastically deformed zone. This in turn increases the resistance of the material to fatigue failure, because any external forces must first overcome these residual stresses.

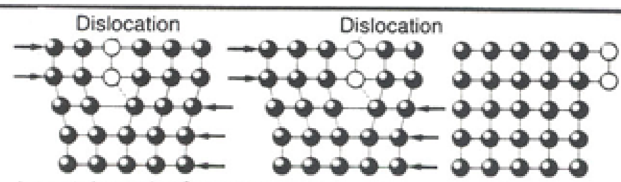




Cracking that occurs due to the interaction between static tensile stresses in the metal and a corrosive medium is called stress corrosion cracking. During roller burnishing, these tensile stresses are eliminated when the material is compressed. At the same time, pits, scratches and porosities in the surface, which could otherwise collect reactive substances and contaminants, are eliminated. Roller burnishing thereby increases the corrosion resistance of the material.

Workhardening

A metal lattice is never completely perfect. It always contains built-in irregularities of various types. These socalled dislocations reduce the strength of the material, since less force is required to alter the atomic lattice. In the figure, we see that there is an extra atomic plane in the lattice. This is a type of dislocation. Upon application of an external load, less force is required to deform the lattice than if it had been perfect. An attempt is made to inhibit the movement of the dislocations by means of different hardening procedures.



Atom deformation facilitated by dislocation movement

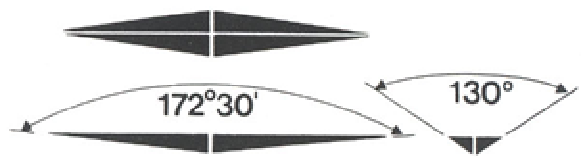
Cold working increases the number of dislocations, and the material should become softer. The effect is the opposite, however. Because there are so many dislocations, they prevent each other from moving. This is what happens in roller burnishing. The material is displaced and becomes harder and stronger due to work hardening, where the movements of the dislocations are obstructed.

INCREASE IN SURFACE HARDNESS

Material	Bore Diameter (mm)	Altered diameter (mm)	Increase in Hardness
Steel	5	0.012	14 R/C
	10	0.018	(212 BHN)
			to
	25	0.025	30 R/C
	50	0.05	(286 BHN)
Stainless Steel	5	0.012	20 R/C
	10	0.02	(230 BHN)
			to
	25	0.025	42 R/C
	50	0.04	(400 BHN)
Cast Iron	5	0.012	6 R/C
	10	0.015	(180 BHN)
			to
	25	0.025	25 R/C
	50	0.04	(250 BHN)
Aluminum	5	0.015	100 BHN
	10	0.025	
			to
	25	0.04	
	50	0.04	120 BHN
Bronze	5	0.018	134 BHN
	10	0.025	
	25	0.03	
	50	0.025	186 BHN
Brass	5	0.012	115 BHN
	10	0.012	
			to
	25	0.02	
	50	0.04	150 BHN

The hardness increase varies, depending upon the material that is being roller burnished. The table below shows examples of hardness increases in Rockwell C and Brinell brought about by the roller burnishing of different materials.

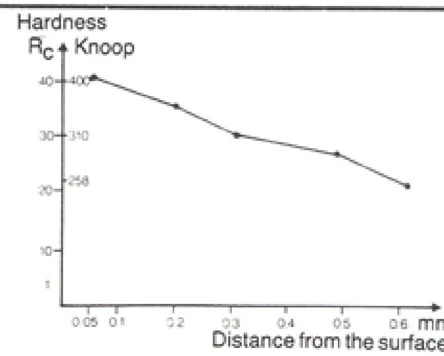
Because we are dealing with surface hardness, the hardness increase cannot be measured by means of Rockwell or Brinell testing. Instead, a method known as Tukon testing is used. In the Tukon test, a pyramid-shaped diamond is used (see the figure). The Knoop value is obtained by measuring the length of the impression. The load under which the impression is made varies between 1 and 500 grams. Knoop values can be converted to Brinell or Rockwell hardness, which are more widely used measures.



KNOOP INDENTATION

KNOOP HARDNESS	ROCKWELL	BRINELL
410	41	382
400	40	371
353	35	323
310	30	281
281	26	268
258	22	232

The hardness of some etched cross-sections from different materials subjected to roller burnishing has been tested at different distances from the surface. The Knoop hardness measurement shows a clear hardness increase at the surface, with hardness gradually decreasing to the original value at greater distances from the surface.



BORED

BURNISHED