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Hard Tools for a Fine Finish

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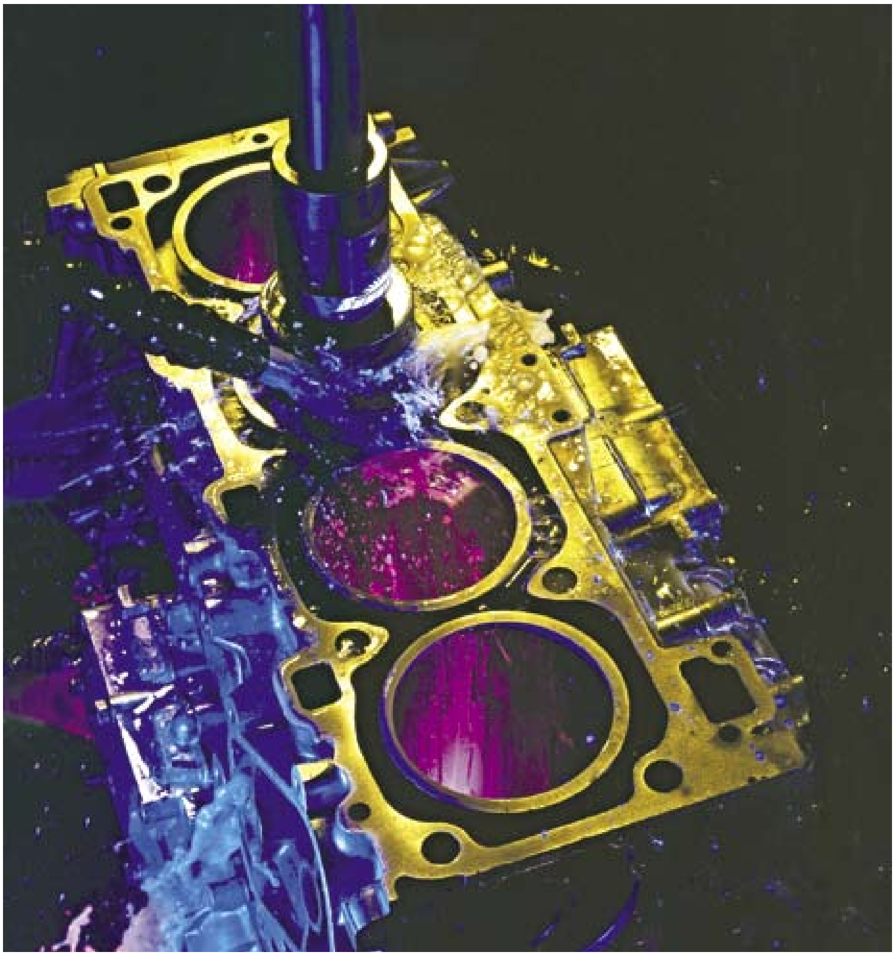
Superhard tool materials for automotive honing applications.



Sunnen Products

Engines have always been honed to precision specifications for bore geometry and surface finish to increase power output and life.

Honing and otherwise finishing automotive components using cutting tools made of superhard materials leads to process improvements. Research, development and implementation of superhard materials and the cutting tools made from these materials are an important part of the production of high-quality parts.

The main approach toward improvement in automotive metalworking applications is based on achieving accurate and high-quality parts and maximizing productivity during machining.

Applications for diamond and polycrystalline cubic boron nitride tools include:

- Honing of cylinder liners, piston rings and cylinder sleeves for internal combustion engines,
- Honing of holes in universal-joint forks,
- Gear grinding, and
- Smoothing of engine parts.

Parts in the cylinder piston group of combustion engines work under heavy loads. Cylinder liners and piston rings are subjected to significant heat and mechanical loads in this chemically aggressive environment. Predominant types of wear for rings and liners are molecular adhesion, abrasion and fatigue failure. Cycling loads acting on the surfaces of liners and rings generate alternating mechanical and heat stresses. Achieving effective performance of the cylinder liner and piston ring pair requires eliminating molecular adhesion between their surfaces, obtaining high wear resistance and reducing the coefficient of friction. All these can be achieved by imparting the required roughness, or finish, on the contact surfaces.

Honing

Development of honing of cylinder liners with diamond tools is based on plateau honing technology. Plateau honing produces a microfinish free from surface peaks but containing deep valleys. Such valleys act as oil reservoirs for improved lubrication. Oil-retaining valleys with a large contact surface significantly reduce the engine break-in period and oil consumption and significantly increase engine life through greater cylinder liner wear resistance. The wear resistance of a plateau-like surface with optimal roughness (measurements given below) is several times higher than that of a surface with roughness of 0.16μm R_a to 0.32μm R_a (6.3μin. R_a to 12.6μin. R_a), and the engine break-in period is reduced by half.

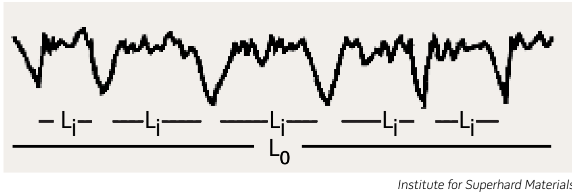


Figure 1: Profile of the effective surface of a cylinder liner after plateau honing.

An optimal microfinish produced by plateau honing (Figure 1) has the following parameters:

■ Supporting length of the profile is 50 to 60 percent at the level of 1μm to 2μm (39μin. to 78μin.). As shown in Figure 1, the supporting length of the profile, or supporting area, is $\Sigma L_i \div L_0 \times 100$ percent, where ΣL_i is the sum of distances between the valleys measured at a depth of 1μm to 2μm from the cylinder liner's working surface, and L_0 is the profile's total length.

■ Depth of a valley (oil reservoir) is 2.5μm to 10μm (0.0001" to 0.0004").

■ Width of a valley is 15μm to 30μm (0.0006" to 0.0012").

A rough surface is formed during preliminary honing with diamond stones having a grain size of 125/100 to 250/200. In this operation, a metallic bond retains diamond grains in the stones. During the final stage of machining, microprotrusions on the cylinder's surface are cut down to create a surface consisting of wide plateaus. Diamond stones with a smaller grain size and an elastic, rubber-containing bond are applied for microhoning.

Engine performance at extreme loading conditions generates high temperatures that cause the oil film on the cylinder liner to break down, producing dry and semidry friction. Therefore, heat-resistant solid lubricants must be delivered to the friction zone. This can be accomplished by various methods, one of which is a finishing antifriction nonabrasive treatment. Using this method, a thin layer of brass, bronze or copper in a glycerin medium is deposited on the working surface. Under friction, an oxidant film on the part's surface is dilated and the copper alloy is plasticized, which makes it adhere to the substrate. This method increases wear resistance of the cylinders by 1.5 times compared with conventional diamond honing.

Diamond plateau honing has been improved by implementation of plateau antifriction honing, based on applying a solid lubricant coating onto a cylinder liner's surface after this surface is rough honed with diamond stones having a grain size of 125/100 to 160/125.

Rough honing operations produce alternating deep valleys to retain oil and plateaus to maintain the necessary length for supporting the surface profile.

Rough honing operations produce alternating deep valleys to retain oil and plateaus to maintain the necessary length for supporting the surface profile. Using the friction method, diamond stones can be used to apply a special composite coating consisting of copper, zinc, graphite, molybdenum disulfide and other components. Such a coating is characterized by its low coefficient of friction, chemical affinity with iron, high plasticity and corrosion resistance. Using this coating, an engine's performance can be maintained at a low coefficient of friction between the piston ring and the cylinder liner.

Plateau antifriction honing technology can be also implemented when honing using diamond stones with grain sizes of 100/80 to 80/63.

Automotive machine shops use diamond honing to machine holes in hinged-type connecting rods made of alloy steel hardened to 241 to 277 HB. This steel's chemical composition is roughly equivalent to AISI 6150 chromium-vanadium alloy steel. The obtained surface roughness is 0.5µm R_a (19.7µin. R_a), and the out-of-roundness and taper are equal to or less than 12µm (0.0005") for a length of 41.5mm (1.63"). Such surface parameters are produced using a rigid stone and floating part.

Preliminary honing is produced using diamond stones measuring 125mm×10mm×5mm (4.92"×0.39"×0.20"), which have a 3mm-thick (0.118") layer of synthetic diamonds and a 40mm (1.575") radius of curvature. The synthetic diamond grain size is 100/80, and the concentration of diamonds in the binder is 50 percent.

Final honing is done with stones containing fine synthetic diamonds having a grain size of 28/20 and a metallic binder. Machining removes 0.08mm (0.003") of material in 45 to 60 seconds to impart a surface roughness of 0.20µm R_a to 0.63µm R_a (7.9µin. R_a to 24.8µin. R_a).

External honing of chrome-plated piston rings is performed on a single-spindle honing machine with diamond stones measuring 100mm×12mm×6mm (3.94"×0.47"×0.24"), which have a 3mm-thick (0.118") layer of synthetic diamonds, 50 percent concentration and a metallic binder.

Diamond stones with a 63/50 grain size are applied for preliminary honing of the piston rings, and 28/20 diamond stones are used for finishing. The machine's capacity is 800 piston rings per shift. Tool life of a set of these diamond stones is 15,000 honed piston rings.

Diamond Elastic Stones

Diamond elastic stones and cloths are used for finishing operations and provide significantly longer tool life than conventional abrasive polishing tools. When crankshaft pins are polished with diamond cloth, roughness of 0.16µm R_a to 0.32µm R_a (6.3µin. R_a to 12.6µin. R_a) is reduced to 0.08µm R_a to 0.16µm R_a (3.15µin. R_a to 6.3µin. R_a) in 20 to 30 seconds. A diamond cloth can polish 30,000 to 50,000

keyword

FINISHING: Any of many different processes employed for surface, edge and corner preparation, as well as for conditioning, cleaning and coating. In machining, usually constitutes a final operation.

—CTE Metalworking Glossary

crankshaft pins.

The 130mm-long (5.12") diamond cloth substitutes for a 100m-long (328') standard abrasive belt, meaning tool life of a diamond cloth is about 770 times longer than a standard abrasive belt.

Diamond cloth also substitutes successfully for abrasive stones when used on superfinishing machine tools. One 65mm-long (2.56") diamond cloth substitutes for 20 to 30 sets of abrasive stones, with two stones per set, when polishing crankshaft cams. Using the diamond cloth, surface roughness of crankshaft necks can be reduced in 30 to 40 seconds from a range of 0.63µm R_a to 1.25µm R_a (24.8µin. R_a to 49.2µin. R_a) to 0.16µm R_a to 0.32µm R_a (6.3µin. R_a to 12.6µin. R_a).

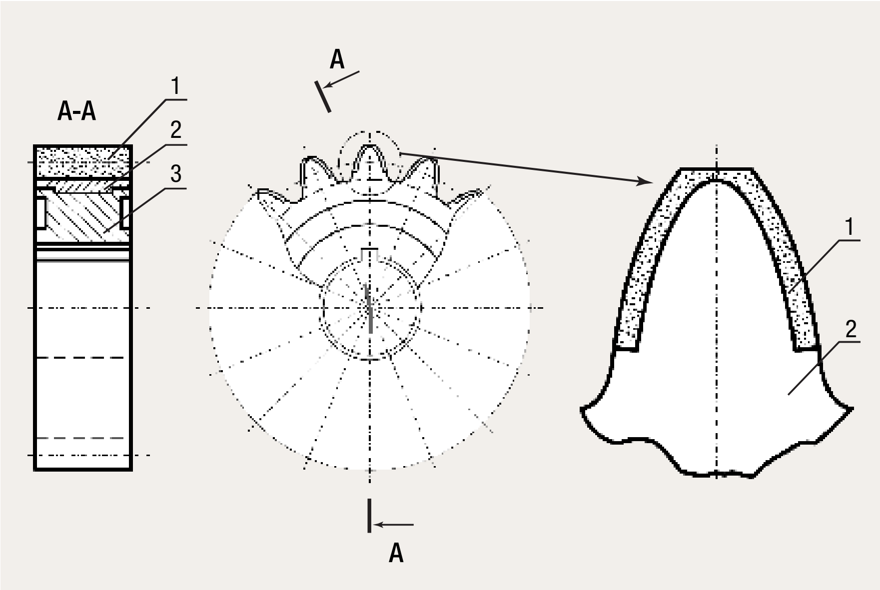
Advanced diamond polishing is achieved with diamond elastic stones for superfinish honing of cylinder liners. The stones' elasticity is achieved by a special binder that contains rubber and polymer. Such operations take about 15 seconds to remove 5µm to 7µm (0.0002" to 0.0003") of material. A surface roughness of 0.32µm R_a to 0.63µm R_a (12.6µin. R_a to 24.8µin. R_a) can be reduced to 0.08µm R_a to 0.16µm R_a (3.15µin. R_a to 6.3µin. R_a). One set of diamond elastic stones can hone up to 150,000 cylinder liners, which provides 1,000 times longer tool life than standard abrasive hones.

Gear Honing

Gear honing and gear shaving have similar kinematics, but gear honing is more efficient. Gear honing imparts a finer finish on a tooth's working surface, removes burrs and nicks and reduces dimensional inaccuracy caused by heat treatment. Traditional abrasive gear hones exhibit low wear resistance and insufficient teeth strength. Therefore, abrasive honing cannot provide an economically feasible operation.

Diamond gear hones are free of these defects. Improved cutting ability, high strength and high wear resistance make diamond gear hones quite effective. A diamond hone's tool life is about 10 to 15 times longer than an abrasive hone's.

A spur gear hone with a 4.25mm (0.167") module and 20mm (0.787") face width is shown in Figure 2. It con-



Institute for Superhard Materials

Figure 2: A spur gear hone, where 1 is a diamond layer with metallic binder, 2 is a metallic body and 3 is a metallic hub.

sists of a 1.0mm-thick (0.04") diamond layer with metallic binder deposited on the face of each tooth (position 1), a metallic body (position 2) and a metallic hub (position 3). Such diamond tools are used for honing transmission gears made of alloy steel hardened to 58 to 62 HRC, which is roughly equivalent to AISI 4320 nickel-chromium-molybdenum alloy steel. Hones containing a diamond layer with a 63/50 grain size or finer and a diamond concentration of 100 percent produce a surface roughness of 1.2µm R_a (47µin. R_a).

Diamond elastic stones and cloths are used for finishing operations and provide significantly longer tool life than conventional abrasive polishing tools.

Diamond gear hones used for finishing spur gears (56 to 62 HRC, 4.25mm module) have shown high productivity. Tool life of one such gear hone was 4,000 to 5,000 gears while average tool life for a standard abrasive gear hone is 300 to 350 gears.

Application of the same diamond gear hones, but with elastic binders, to machine the same gears results in honing at least 80 percent of a tooth's face area. This compares with 70 percent of tooth face area honed by diamond gear hones with metallic binders. An elastic binder makes hones more flexible, reduces machining pressure and increases the efficiency of a machine tool.

Diamond Smoothing

Diamond smoothing expands the technological possibilities for finishing operations. It improves the service life of engine components by strengthening a metal's superficial layer and increasing its microhardness by 10 to 15 percent. Strengthening of a superficial layer and increasing its microhardness are the results of a change in microstructure due to applied pressure by the smoothing tools. Diamond smoothing produces a surface roughness of 0.16µm R_a to 0.63µm R_a (6.3µin. R_a to 24.8µin. R_a). Smoothing tools are made of synthetic and natural diamonds and are characterized by high hardness, low coefficient of friction, high thermal conductivity and a fine finish.

Diamond smoothers with cylindrical or conical working surfaces are used for external cylindrical surfaces, and smoothers with spherical working surfaces are used for internal surfaces. Diamond smoothing is performed on lathes. A part to be smoothed is fixed in a chuck or a dead center, and a fixture for a smoothing tool is placed in a toolholder.

Smoothers containing natural diamonds have the longest tool life. However, smoothers containing synthetic polycrystalline black, or carbonado-type, diamonds have been successfully applied when smoothing parts made of a grade-40 steel hardened to 169 to 203 HB (equivalent to AISI 1045 medium-carbon steel). A synthetic PCD smoother's tool life is 150 parts.

In some cases, diamond smoothing is more effective than superfinishing and polishing. Diamond smoothing instead of superfinishing a turbine's shaft necks increases the parts' superficial microhardness by 10 to 15 percent, producing a 40 to 60 percent increase in wear resistance. In addition, out-of-roundness and taper are within 20μm (0.0008"). Machining time per part is reduced from 6 minutes to 3 minutes.

When it replaces polishing, diamond smoothing of a gasket's surface of a cardan shaft eliminates oil leakage through the gasket due to the formation of an augerlike microtexture with a direction opposite of the flange rotation. This surface diverts oil back into the gasket.

Tools made of polycrystalline superhard materials are used for machining parts—pistons, plungers, rotor caps, gears, bushings, valve seats and cylinder blocks—made of hardened steels, cast irons, aluminum and copper alloys. Inserts made of kiborit (a CBN material) exhibit long tool life when high-speed semifinish and finish turning steel and cast iron parts. The kiborit inserts replace machining using cemented carbide inserts and grinding and nearly double machining productivity.

Cutting tools made of polycrystalline superhard materials improve the quality of machined parts, significantly increase tool life, reduce resharpening costs compared with carbide tools and reduce tool-change time. **CTE**

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