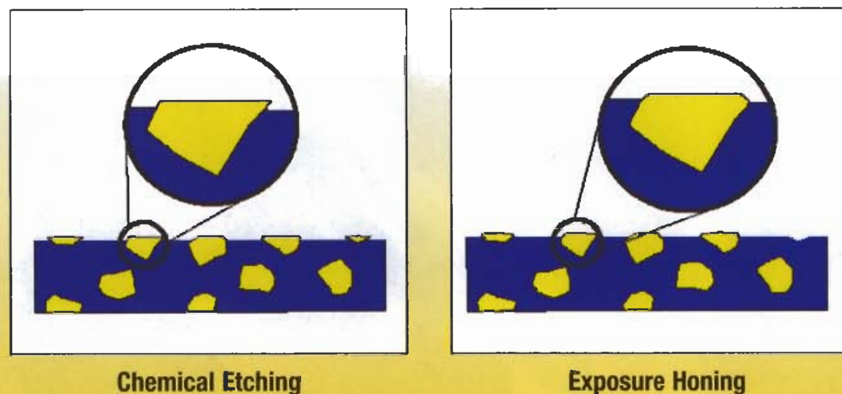
Exposure Honing of Hyperutectic Al-Si Alloys

BY **SANJAI KESHAVAN** AND **CHRIS SAUER**

The main objective of going to a light metal crankcase include reducing weight, space, friction and oil consumption. Manufacturers of Al-Si alloys each have their own variations on the material, but are all based on a common premise; the piston ring travels on silicon particles which protrude above a base aluminum sub-surface. The degree of silicon protrusion, or more commonly referred to as the amount of exposure, above the aluminum sub-surface and how this can be cost effectively obtained by mechanical honing is the focus of this article.

Hard silicon particles are either mixed in the base metal during casting or applied in a secondary operation. Following are some of the common way of accomplishing this:

1. Hypereutectic "$AlSi_{17}$" alloy produced by low pressure / gravity die casting, e.g. Alusil, Silumal, Mercury alloy
2. Infiltration materials with ceramic particles and / or fibres, e.g. Lokasil (squeeze casting, reaction infiltration)
3. Addition of reactive components in the molten metal, e.g in situ formation of TiB_2
4. Mixing inert hard materials (Al_2O_3, SiC into the light metal melt, e.g. Duralcan)
5. Powder-metallurgical materials (sintered) from LM powders and various ceramic powders (Si, SiC, etc.)
6. Spray compacting a) hypereutectic alloys ($AlSi_{25}$) e.g. "Silitec"
7. Fine-grained, hypereutectic AlSi alloys by suppressing the Si crystal growth and then heat treatment
8. Laser alloying of Al blocks by adding Si powders (or similar material)
9. Laser depositing of AlSi alloys
10. Electro plating – e.g. Ni-SiC (Nicasil)



The chemical etching process leaves a sharper silicon edge. The Nagel exposure honing technique tends to round off the sharp silicon edges. This is beneficial for the engine as a rounded off edge is less likely to get dislodged.

Silicon Exposure – Chemical vs. Mechanical Exposure

Exposing the very fine silicon grains is the final phase of the bore finishing process and involves relieving the aluminum sub-surface of the bore without damaging or removing the silicon particles. The amount of relief or distance between the surface of the silicon particles and the aluminum sub-surface is critical. The process(s) employed to achieve this must be repeatable and controllable, as this area provides the required oil retention necessary for cylinder bore and piston ring lubrication.

In current production applications, two methods of silicon exposure are being used; mechanical and chemical etch. The mechanical method employ either a conventional hone used with lapping type compounds or Nagel exposure hone process that does not require such lapping type compounds. The chemical process uses an acid solution at a low concentration applied directly on the finish honed cylinder bore surface for a predetermined amount of time to chemically etch away the aluminum sub-surface around the silicon particles. Both mechanical and chemical exposure processes are being used successfully in production. It is advantageous to eliminate chemical etching as it adds another step in the manufacture of the cylinder.

Silicon exposure depths of production Al-Si engines range from 0.25 um to 0.70 um. The amount of silicon exposure obtainable from the mechanical hone process is generally less than that obtainable with chemical etching and is proportional to the grain size of the silicon particles. The amount of exposure generated by the chemical process is dependent on the type and strength of the solution employed and duration of exposure and is less dependent on material composition. As illustrated above, the chemical etching process leaves a sharper silicon edge and Nagel exposure honing technique which tends to round off the sharp silicon edges. This is beneficial for the engine as a rounded off edge is less likely to get dislodged.

Honing Al-Si Cylinder Bores

The Nagel Al-Si honing process utilizes three separate passes; rough, semi-finish, and a mechanical exposure pass. Rough honing, as with any cylinder hone process, is used to remove prior boring operation surface deformation and improve cylinder geometry in preparation for the finishing passes. The semi-finish hone pass further reduces surface deformation, continues to improve bore geometry, and generates the final bore diameter. Unlike a conventional cast iron process where the finish hone pass continues to further improve bore characteristics, the Al-Si process requires the semi-finish pass to obtain all the required finish honed bore characteristics. The function of the final exposure pass is only to provide the required silicon exposure.

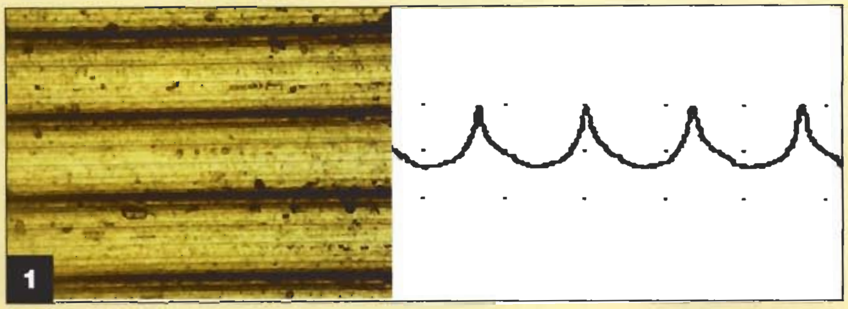
Nagel ECO Hone designed for exposure honing.

Nagel refractory abrasive designed for exposure honing.

1) Finish Bored – Incoming to Honing RA = 4.5 um

Incoming, finish bored Al-Si liner condition is typical of many finish boring applications, presenting no difficulties for the hone process.

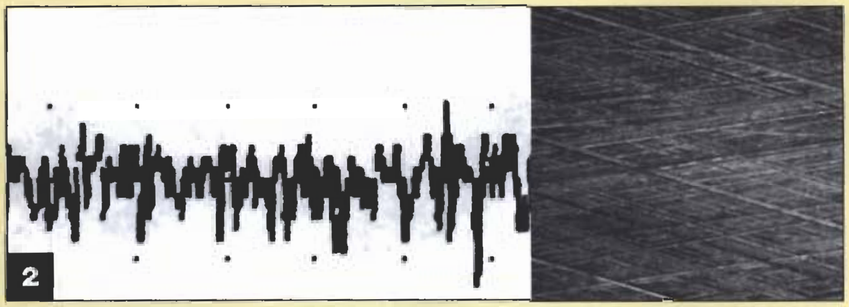
Both the rough and semi-finish honing processes employ diamond super abrasives in a very friable bond. The crystal mesh size used is considerably finer than typical cast iron applications, as the Al-Si material is easily machined.



2) After Rough Honing
(200x magnifications)

Ra	0.40 um
Material Removal (dia)	0.075 mm
Cylindricity	11.9 um (typ)
Hone Time	24 sec.

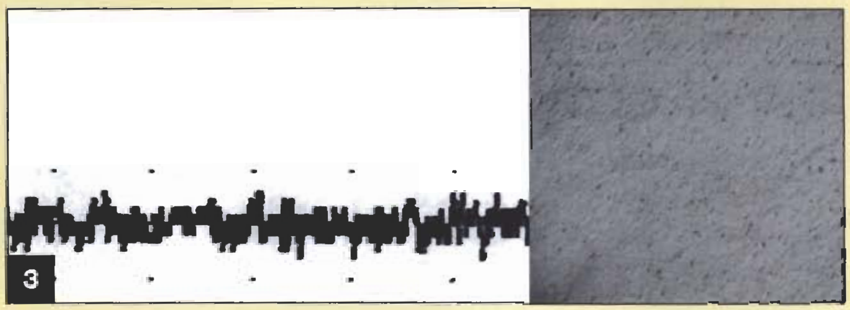
The semi-finish hone pass produces a surface roughness measurably smoother than the exposure or finish hone pass. This difference is a result of the unexposed condition of the silicon particles. Note the absence of the typical cross-hatch pattern.



3) After Semi-Finish Honing
(200x magnifications)

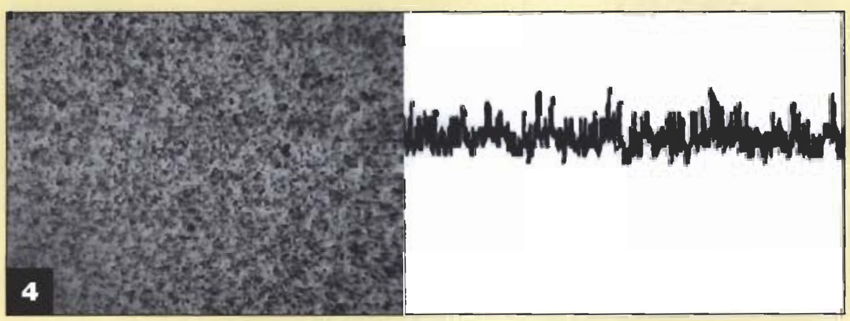
Ra	0.03 um
Material Removal (dia)	0.015 mm
Cylindricity	7.1 um (typ)
Hone Time	24 sec.

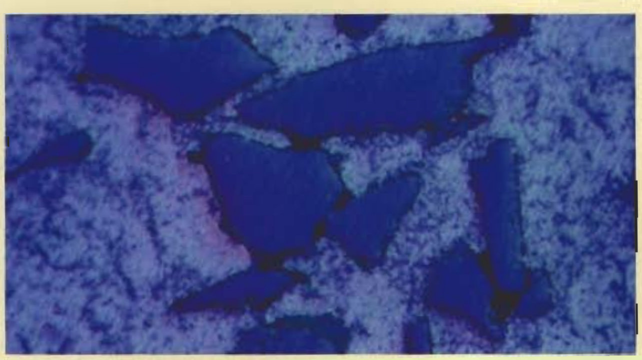
After exposure honing, the surface roughness is measurably coarser and the exposed silicon particles are clearly visible.



4) After Exposure Honing
(200x magnifications)

Ra	0.09 um
Material Removal (dia)	0.001 mm
Cylindricity	7.1 um (typ)
Hone Time	40 sec.





This SEM micrograph illustrates exposed Si surface after Nagel Exposure honing process.

A combination of latest machine controls such as servo expansion, servo rotation, servo stroking and spindle design that provides specific speeds, feeds and direction of rotation coupled with refractory type abrasive material designed specifically to work in conjunction with ECO hone is at the heart of exposure honing technique.

Using this approach eliminates the need for both:

A) Adding abrasive lapping compounds which has detrimental effect on machine wear, adds costs as a reliable system to introduce abrasive compound is needed and pollutes the coolant system as; and

B) Extra costs involved due to adding an extra chemical etching process.

EXPOSURE HONING

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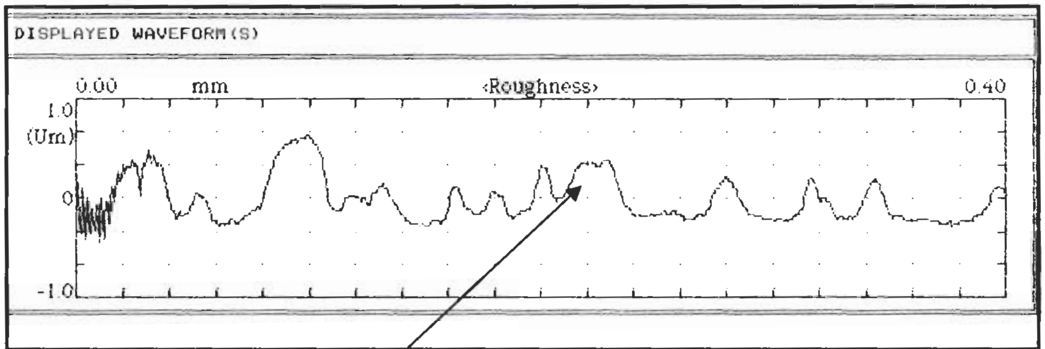
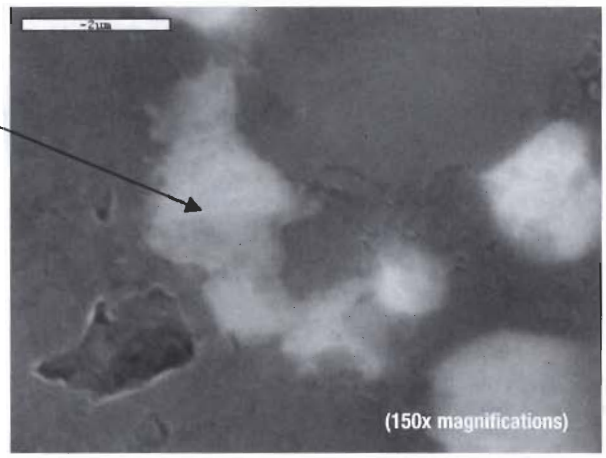


EXPOSED SILICON



Exposure Honed Profile

The silicon particle height can be extrapolated from the profile representation, however measurement in this manner is tedious and only a minute portion of the measured profile can be viewed at a given time. None of the typical surface finish parameters, statistical or those derived from the bearing ratio curve, provide an accurate description of silicon exposure depth. In an attempt to quantify exposure depth, and in a standardized format, the industry has adopted the parameter Rf.

Measuring Silicon Exposure

A representation of the exposed surface can be obtained with stylus type surface finish profilometers providing the compatible software has the capability to magnify the displayed surface profile as shown above.

The Rf parameter is derived through the calculated difference between the average height of the exposed silicon particles and the average height of the measured aluminum sub-surface. Numerically, Rf is expressed as:

$$R_f = \overline{X_{Si}} - \overline{X_{Al}}$$

Rf has been defined as the difference between the modes of the typically bimodal distribution (histogram plot) generated from the exposed surface profile data.

Manufacturers of surface finish measurement systems have made the Rf parameter available on their newer instruments.

Other issues pertaining to the use of this calculation are: An inability to directly correlate or relate Rf to standardized surface finish parameters.

The calculated Rf value is dependent on the method of silicon exposure employed; mechanical or chemical.

The inability to directly correlate or relate this new parameter to standardized surface finish parameters, combined with the absence of an international standard for the algorithm used to calculate Rf, introduce a degree of uncertainty when attempting to quantify the performance of the hone process.

Of the standardized surface finish parameters, the Rz parameters, specifically R3Z and RZ(DIN), are probably the closest approximations to Rf, by definition. However, the Rz measurement is based on relatively few peaks (silicon particles) and tends to be significantly higher than the measured Rf value.

The method of silicon exposure, mechanical or etch, employed can affect the calculated Rf value. The mechanical exposure process has a tendency to round off the edges of the silicon particles during honing.

ECO Series 80 & 180 Engine Block Honing System

An economical system combining roughing, finishing and gauging in one station is a distinctive capability of the ECO 80 & ECO 180 dual-expansion honing systems has recently been developed.

This system was specifically designed for low and medium volume engine, turbine and hydraulic pump OEM manufacturers as well as repair shops. It provides the features of a multi spindle/station machine in a single spindle package and the benefits of in-process gauging and tool wear compensation.

Traditionally, engine block / liner honing consists of at least two passes, first with a rough stone and then with a finish stone. A post process gauging station monitors the tool wear and compensates for it. All these operations occur in an elaborate transfer type machine. Cost of the equipment is justifiable if volumes are sufficient to keep the utilization levels high. However repair shops and low/medium volume production OEM's resort to batch production and manually

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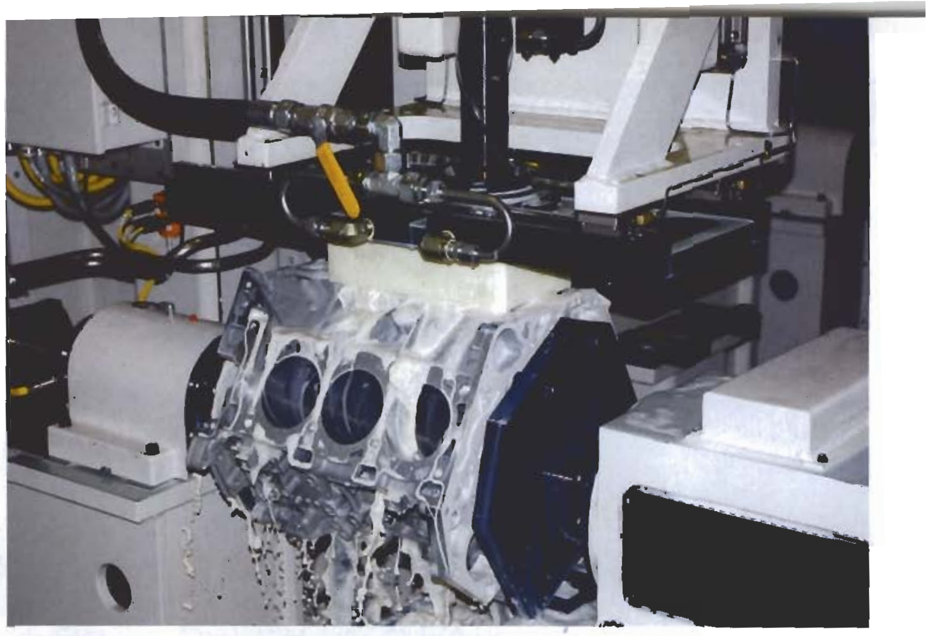

Pictured right, a V6 Block being honed by a dual expansion honing tool with in-process gauging. The servo controlled fixture automatically presents all bores under the honing tool.

ECO 80 can finish bore sizes ranging from 10 to 80 mm and ECO 180 can finish bore size ranging from 40 to 180 mm. The dual-expansion system on the ECO series allows tools with different grit sizes to be mounted on the same spindle.

ECO Dual expansion tool performs roughing, finishing and gauging.

measuring the bore and compensating for the tool wear, which costs them dearly in terms of productivity and quality.

ECO 80 can finish bore sizes ranging from 10 to 80 mm and ECO 180 can finish bore size ranging from 40 to 180 mm. Honing systems typically require separate stations for roughing and finishing because each operation requires different grit sizes on the respective diamond honing tools. The dual-expansion system on the ECO series allows tools with different grit sizes to be mounted on the same spindle. Separate systems control the mechanisms within the spindle that expand the roughing and finishing tools. The expansion for roughing is driven by servo motors, whereas the expansion for finishing is hydraulically actuated. The finish honing operation commences automatically after the roughing operation reaches the pre-determined bore size. An automatic tool wear compensation system links in-process gauging with the honing spindle. By gauging every part, bore size can be monitored continuously and submicron adjustments can be made to honing parameters to compensate for tool wear.

This approach is an improvement over manual compensation systems typically found on other equipment for low- and medium-volume applications, in which over- and under-compensation is a problem.

The tool wear compensation system is designed to further reduce non-cutting time while improving bore quality. Once inserted in the bore, the tool expands at a "rapid" feet rate of 200 microns per second at 45 percent of available torque until it reaches a pre-determined bore size close to the desired limit. It then switches to an expansion rate of 4 microns per second at 15 percent of available torque to avoid tool damage. Toward the end of the program cycle, the tool expands at only 2 microns per second at about 10 percent of available torque. The system constantly monitors both the tool expansion rate and percentage of available torque. The operator can reduce the tool expansion rate for tighter tolerances or increase the torque for faster cycle times. This yields a more consistent bore in terms of finish, size and cylindricity.

The post-process gauging system automatically checks the bore for form errors such as taper, hourglass, barrel shape, ovality and others. Automatic adjustments correct for the specific kind of error detected.

Loading and unloading can be automated or accomplished manually. ■

Sanjai Keshavan (left) and Chris Sauer (right) have more than 35 years of combined service in the super finishing and honing industry. They're both currently employed by Nagel Precision, Inc., a world leader in supplying honing and super finishing equipment that recently has developed equipment for lower volume shops.

For more information, contact Nagel Precision Inc., Ann Arbor, MI. Website: www.nagelusa.com.