Abradable Piston Coatings

Better fit for more power and durability

BY **ANDY SUMAN**

All the power an internal combustion engine will ever make is captured by the piston-ring assemblies. It follows that any refinement in the fitting or sealing of a piston assembly in its mating bore has potential to deliver benefits in the performance and life of a cylinder kit. Abradable Powder Coatings (APC's) on piston skirts and lands are advancing performance and life of cylinder kits in three principal ways:

1. APC coatings lap in to permanently improve piston-to-bore fit, reducing unwanted motion and creating a thin, resilient oil film for lower friction with less wear.

2. Better piston fit in each bore keeps rings square to the cylinder and settled for improved sealing, heat transfer and oil management.

3. All across the skirts (not just at the gage point) APC safely removes Integrated Skirt Clearance (ISC) volume between piston skirt and bore surface to limit destructive motion and accelerations between cylinder kit components.

Here's how they work:

APC's are made of plastic and graphite, and are applied in thicknesses up to .015" and more on the diameter of a piston skirt and sometimes on the lands. 75-80% of the manufacturer's recommended piston to wall clearance is filled with the abradable graphite coating at the time of engine assembly. During initial operation, the piston gets too tight in some areas, causing the coating to abrade away in that spot. Once there is room for the ideal oil film over the entire skirt, the wear stops and the perfect shape is locked in for the life of the piston. This self-fitting, lapping process is dubbed Stribeck Fitting, as shown in Figure 1.

Fig. 1: Stribeck Fitting sequence

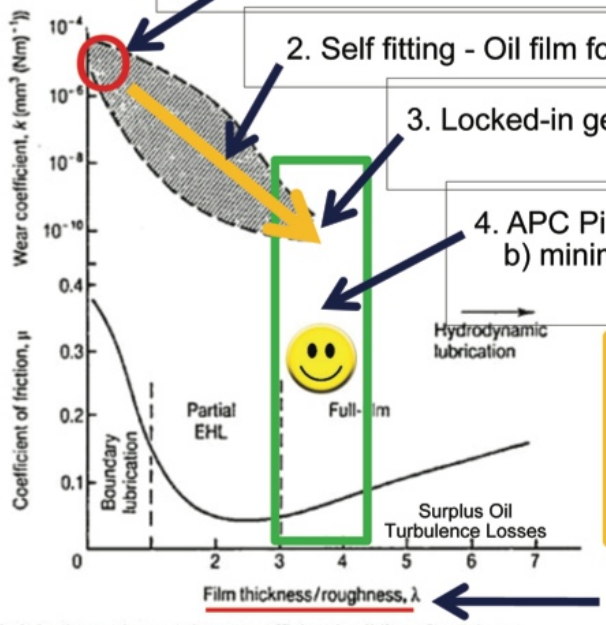
In an operating engine, APC will find and preserve the lowest friction piston geometry for each bore.

1. Build tight across entire skirt. At start-up, rapid, friendly wear-in

2. Self fitting - Oil film forms and wear rate asymptotically declines

3. Locked-in geometry - When there is just enough room for a stable oil film, the wear stops

4. APC Piston has: a) minimized secondary motion
b) minimum oil film thickness for lowest friction
c) no boundary lubrication



Lubrication regimes and wear coefficient in sliding of metals, as a function of λ (reproduced from Hutchings, 1992).
source: www.scielo.br/img/revistas/jbsmse/v29n1/a09fig02.gif

Final shape is determined at temperature, under load. Friction, wear, and secondary motions of the rotating assembly are minimized. *Engine efficiency and durability are enhanced.*

APC plateaus are polished, so a VERY THIN oil film can prevent asperity contact.

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Side load oil film pressure distribution on normal coating and operationally fitted abradable coating.

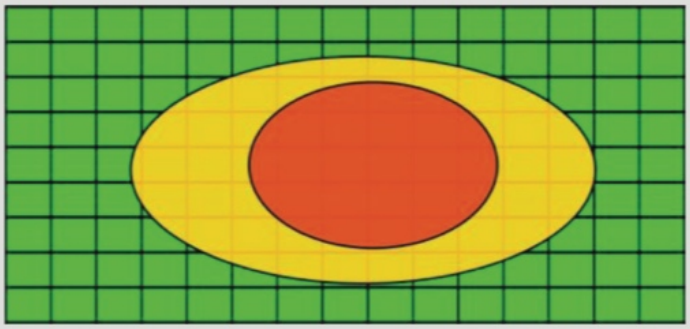

Fig. 2a: Thin, hard coatings concentrate load.

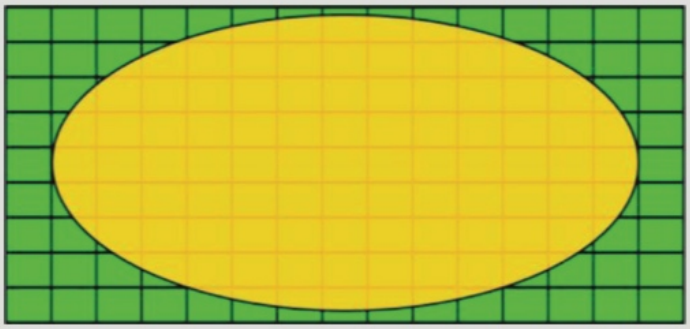

Fig. 2b: Thick, abradable coatings dissipate load.

Once the perfect fit is locked in, the pistons are set at the largest dimensional geometry for each bore that can safely be run without any risk of scuffing.

Figure 2a shows piston contact loading patterns for a regular, thin skirt coating (MOS2), and one with abradable skirt coating after Stribeck Fitting. Notice how the peak load area on the left shows a highly loaded red area and a large green region which carries no load. On the left, the red area is where we see scratches, because the piston occasionally pierces the oil film in this area. Oil film pressure gradients near the red spot allow the oil to flow out so that the piston can touch the bore. This means friction and wear increase! The green area represents extra clearance volume, and is a large reservoir of surplus oil which must also be controlled by the rings.

Above right in Figure 2b, we see a piston contact pattern after Stribeck Fitting during operation with APC. The pressure on oil film on the piston skirt is uniform and stable over a large area of the skirt. The oil film on the right side is very thin, but virtually impenetrable because the oil cannot escape and allow the parts to touch. Friction is low and load carrying is very high for the thin oil film.

The presence of the soft graphite coating on skirts, after extreme performance piston applications, is proof that the oil maintains separation between the coating and the bore.

Figure 3 (below) shows post run abradable skirt pistons after the stated duty cycle. With abradable fitting and a perfect oil film, the pistons, rings, and bore often look dramatically better for wear after the duty cycle.

Fig. 3a: TA2 Piston, 500 race miles.
Courtesy of Prefix Corp & Rafa Matos.

Fig. 3b: 3000hp, blown alcohol, hemi Pro Mod, 40 passes.
Courtesy of Darrell Makins, Under Pressure Performance.

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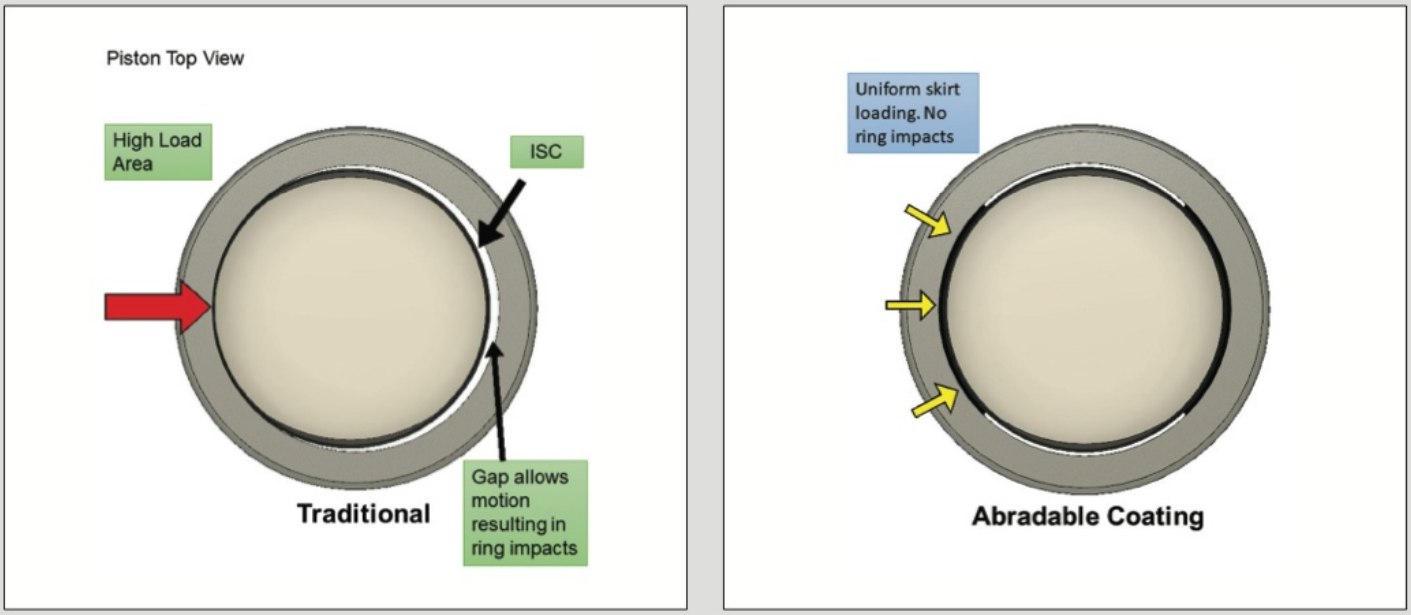


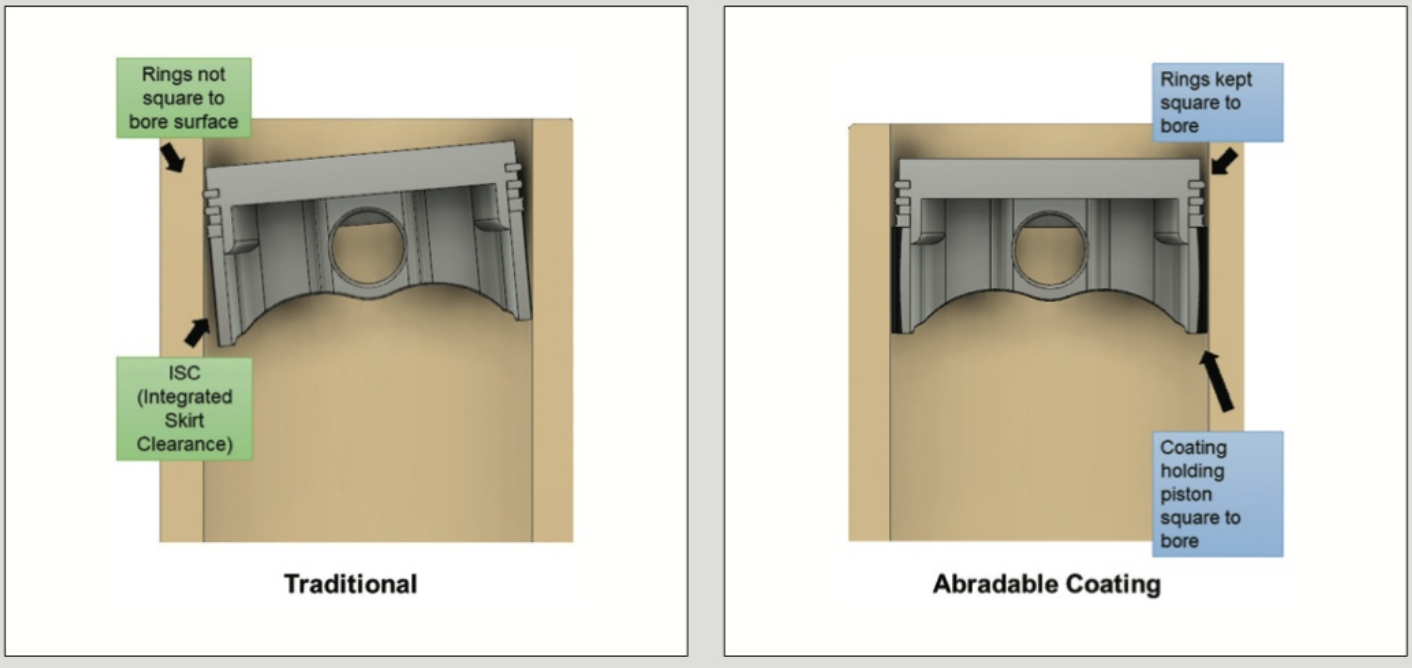
Fig. 4a – Top View

Figures 4a and 4b depict the benefits to the rings from reducing the Integrated Skirt Clearance (ISC) with Abradable Skirt Coatings. If the rings are riding a 'bucking bronco' of a piston, how can we expect them to maintain uniform contact and seal around the cylinder and from top to bottom? These parasitic losses and destructive secondary piston motions occur within the free volume of the ISC. Without ISC volume, bad motions cannot run wild!

If the ISC is largely occupied by the graphite coating, pistons tend to settle down, with less rock and rattle. Importantly, the pistons, ring grooves, and rings are held more squarely to the bore through the entire combustion cycle as shown in Figure 4b.

Furthermore, the rings maintain better seal and oil control if they do not receive shocks and impacts as they ride between the piston and bore. Without shock waves and ring seating reset events, wear modes on the piston-ring-bore system can be dramatically reduced.

Fig. 4b – Side view



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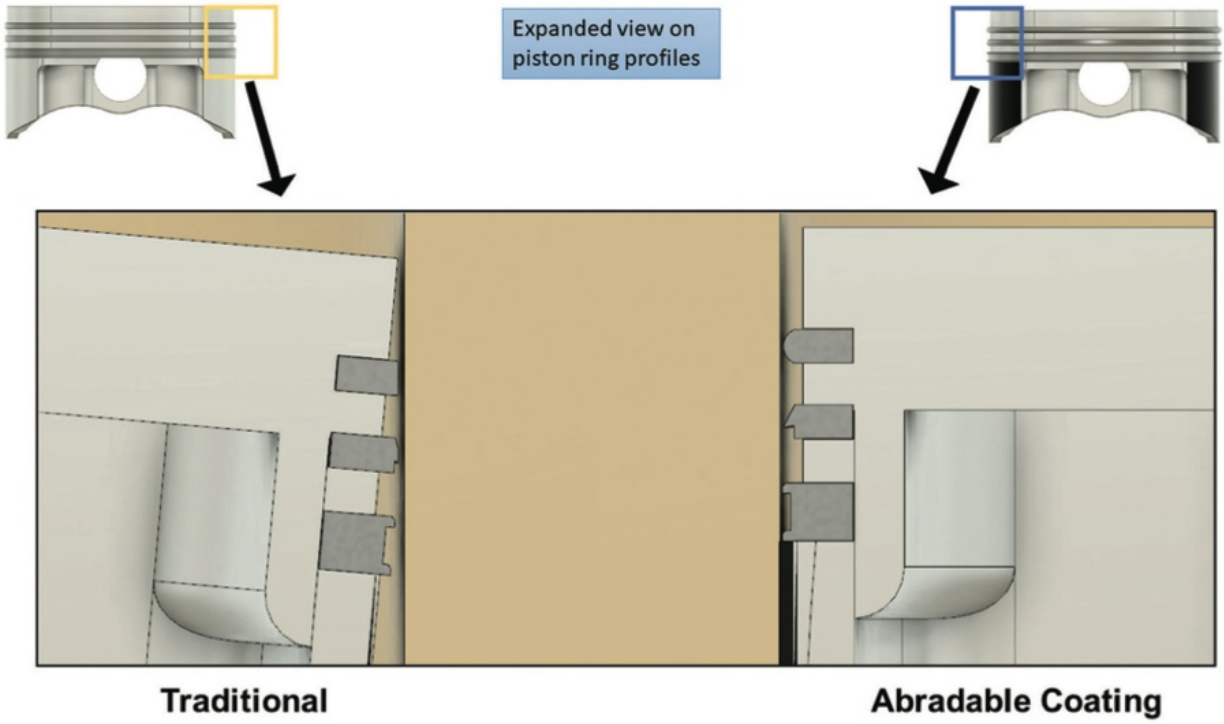

Fig. 5: Stable pistons result in less ring wear.

Secondary motions in ISC gap volume cause components to rattle and rub against each other. When these motions cause mating surfaces to pierce the oil film, friction and wear will occur. Curtailing these motions can eliminate fundamental wear modes in cylinder kits.

Better sealing rings also means less oil fouling from blow-by, not to mention more predictable combustion from cylinder to cylinder, and a longer duty cycle as measured by compression, leak down, or crankcase vacuum. Burning less oil also reduces the formation of hard carbon combustion products which degrade wear interfaces.

Summary

As an engine design feature, abradable piston skirt coatings improve probability of achieving perfect fit and function in every cylinder. APC coatings safely adjust to accommodate natural fluctuations in dimensional stack-up, assembly distortions, thermal gradients and extreme operating conditions. In the end, it's all about the stability of components and oil films if you seek a long lasting, high performing power cylinder.

APC Pistons Field Results

(including 2 strokes, 4 strokes, all fuels)

Cylinder Kit Performance:

- More power
- Less variability in sealing among cylinders
- Better leak-down
- Cleaner combustion (cleaner spark plug)
- Less blow-by
- Consistent combustion and predictable tuning
- Higher oil pan vacuum
- Clean crankcase vacuum tank
- Opportunity to reduce ring tension

Cylinder Kit Life:

- Longer lasting leak-down
- Scuff protection
- Less combustion contaminants in oil
- Cooler running pistons/rings
- Less ring and groove wear
- Reduced oil consumption
- Less bore wear
- Foreign particle tolerance
- Less hard carbon - burned oil particles

On the track, tuning advantages combined with fewer freshen-ups help knowing racers stay in the winners' circle. In volume engine manufacturing, abradable piston skirt coatings reduce risks and make it a little easier to build state of the art power cylinders every day.

Ai Wood, a former Can-Am engine builder and head of DRC Engineering, stated that "having APC in the engine builder's tool kit has been one of the best technical benefits that we've ever experienced."

Andy Suman, President of Line2Line Coatings, has over 30 years experience in engine component materials engineering. Since developing Abradable Powder Coatings for an OEM in 2000, he has pioneered their use in a variety of precision mechanical devices. For more information, contact him at (248) 625-3052 or visit Line2LineCoatings.com. Thanks also goes out to Mark Gelstein markgelstein@line2linecoatings.com and Tom Silvey tomsilvey@line2linecoatings.com for help with information in this article.