DuPont™ Vespel®: Materials to Control Friction – Get Power to the Ground
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(**Science of Fiction**) – I'm Dave Ritchey and I'm pleased to be representing our DuPont Vespel® business in today's webinar. As the leader of our Global Transportation team, I typically hear a discussion that somehow involves controlling Friction every single day – a day just like today. Because of this and the importance of improving vehicle efficiency, we have initiated a program we call "Science of Friction."

Today, I'll give you several highlights on how the Science of Friction has been able to create new solutions to help control friction and get more power to the ground.

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I'll cover three main topics:

- I'll begin with the technology drivers we see in the transportation segment and I hope to give you a feel for why controlling friction is so important.
- Next, I'll review the objectives of Science of Friction and highlight results we've already had in real world applications like transmission seal rings & thrust washers.
- Third, I'll discuss how learnings from these initial successes can be applied to rapidly growing powertrain applications like turbochargers and emissions control devices – both of which need to survive in hot, dirty environments.

And finally, I'll summarize with thoughts on cost and performance benefits.

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By way of introducing the Science of Friction, I'd like to mention that DuPont has a long history of providing materials to control friction – both up and down.

This chart shows a range of resins and additives we produce to control dry friction – and to try to cover the entire 'map' of properties, such as temperature and strength. For example, the addition of Teflon® PTFE does indeed lower friction, while the addition of specially fibers such as Kevlar® can significantly increase friction and improve wear.

One of the technology drivers we see increasing is the ability to have this same control over friction in wet systems – systems which are lubricated with oil, transmission fluid or grease. Simply immersing rotating parts in oil is not good enough today – systems need to be optimized to succeed in the competitive world of fuel mileage targets and emission limits.

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Let's take a closer look at the drivers which are demanding system optimization. First, we've heard from many industry experts and customers that only about 15% of the energy in a liter of fuel makes it to the drive wheels – or said another way, 6 out of every 7 liters of fuel put into a vehicle are lost to inefficiencies.

Connecting that to friction, studies have found that somewhere around 10% of this lost energy is attributed to friction between moving parts. This is a big number – equivalent to several million barrels of oil a day -- and a big opportunity for anyone who can improve control of friction.

These observations made it pretty clear to us that friction – and the ability to control friction - would be extremely important for both existing applications and for the unprecedented number of new powertrain technologies being brought to market today.

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So what does "Science of Friction" mean to us? The easiest way I know to explain it is by looking at a Stribeck curve, shown here in red. This represents friction in a simple rotating disc system. Typically for our experiments we use a metal, like steel or aluminum, sliding against a polymer disc or ring with a lubricant in between such as transmission fluid.

You can see as rotating velocity and loads change, there is an optimum region where friction is at its lowest, shown in the gray circle. Alternatively, friction can be increased, such as on the left side of the curve, to avoid slippage or power loss. Today we'll be focusing on hitting that 'sweet spot' where friction is at its lowest.

Specifically, I'll discuss three variables – material selection, design practices, and temperature – and highlight several of the experimental results we've obtained for our customers. The results I've chosen are based on seal rings and thrust washers – common components in today's drivelines and transmissions.

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First, let's look at how material optimization can improve friction. The first 'output' of our Science of Friction project was actually launched back in April of this year. We introduced a new product designed to help reduce friction – Vespel® SP-2515 – a graphite filled polyimide.

Here are some of the test results. By using a basic thrust washer test we were able to demonstrate a 45% to 55% reduction in friction by using SP-2515 instead of PEEK, even at cold temperatures. This cold temperature improvement could be a significant benefit in cold start or cold environment fuel economy tests.

I'd also like to mention, if you see something that interests you during this presentation, there is much more information available at our website: tryvespel.dupont.com. There you will find these test results and the associated test conditions, as well as data sheets and a technical paper on SP-2515.

(slide 7)
Now let's look at material optimization in combination with design. Here are two separate examples of how careful attention to the details of a component's design – and by taking advantage of a material's properties - can improve friction.

On the left are the results of designing a seal ring to have less contact area with the mating metal surface.

The first observation is based on standard rectangular rings, shown by the blue lines. Please notice that changing only the material to SP-2515 results in about a 13% improvement in torque loss per seal ring.

Then utilizing the high pressure and velocity limits of SP-2515, we designed a "T-shaped" cross section which allowed a smaller contact area. This design change resulted in a combined 34% improvement in efficiency shown by the pink line.

Multiply this savings by the typical 5 to 6 rings used in a modern transmission and the savings can become significant.

On the right, is a similar study, this time looking at the effect of small oil grooves on the face of the seal ring. Here the test used the same two materials, PEEK and SP-2515.

This time the designers optimized the size, shape and number of oil grooves and demonstrated a 50% improvement in the measured torque loss.

Based on results like these, SP-2515 has been recently specified in a new 6-speed automatic transmission for a global automotive OEM.

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While we were developing SP-2515, we noticed a very interesting relationship between temperature and friction. Here the graph shows typical test results when we compared several materials used in friction-control applications.

You can see on the left side, materials such as bronze and PEEK reached high temperatures during the test – high enough to activate our safety interlock system which protects the oil from reaching dangerous temperatures. On the right side you see the results of two grades of Vespel®.

Please notice that SP-2515 not only had the lowest coefficient of friction, it also had measurably lower temperature. In this case, it lowered temperatures by more than 50 degrees C.

In trying to understand the root cause of this significant difference, we also considered that SP-2515 has a very high thermal conductivity – 4 times higher than many conventional polymers.

This led us to question if the lower temperatures we observed were simply the result of lower friction – which in theory would result in less heat generation – or was it also due to SP-2515 being able to conduct heat out of the contact area because of its high thermal conductivity?

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To shed some light on this question, our technical group in Europe devised a clever method to observe the influence of thermal conductivity on a rotating plate-on-disc system. Here is both a sketch and a photograph of our standard thrust washer test equipment.

The equipment has a metal disc which rotates against the thrust washer being tested. The thrust washer is then supported by several metal plates containing a thermocouple and then a polymer insulating disc. The polymer disc serves to block some of the heat flow out of the system.

By replacing this polymer disc with a conductive metal disc, we were able to observe the effect of allowing more or less heat flow out of the system. In this case it would show whether the high conductivity of the SP-2515 could actually be measured, and more importantly, if getting the heat out would actually influence the coefficient of friction.

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Here we can see the results of tests run with this new procedure. The results are pretty dramatic. The graph on the left shows temperature on the vertical axis. The chart on the right shows coefficient of friction. Both were measured simultaneously over the 5 hour length of the test.

First let's look at the blue lines which show the effect of substituting a polymer plate with a metal plate – in both cases using the same Vespel® SP-21 material.

The metal backing plate, which allows more heat to escape, does result in both lower temperatures, shown by the number 1 in a circle, and in a lower coefficient of friction, shown by the number 2 in a circle.

Next let's look at the same test, now using the new SP-2515 material which has higher thermal conductivity. This is shown by the orange lines. Please notice the same trends are observed – lower temperatures and lower friction.

However the new material results in measurably lower temperatures and friction throughout the duration of the test. This supports our belief that 'getting the heat out' allows the system to operate in the 'sweet spot' on the Stribeck curve that we talked about earlier.

So if you have an application where you are concerned about reaching too high of oil temperatures, or not being able to conduct enough heat away from the bearing surface, please contact us – we may have some new options for you.

(slide 11)
Speaking of new options, I'd like to transition away from seal rings and thrust washers, and talk about other applications that may benefit from advances in controlling friction. Specifically emission systems and turbochargers – both of which are seeing rapid growth, both in production volume and in technical advances.

What do these systems have in common? At least three items:

- First, higher temperatures due to the need for higher efficiencies and smaller packaging space.
- Second, there is a high potential for contamination, both from exhaust gas contaminates such as coke or carbon particles, or from exposure to dirt and chemicals in the engine compartment like fuels or solvents.
- And finally, with the drive to reduce weight, there is an increase in the use of lighter weight metals or plastic.

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In several commercial applications, we have observed a unique property of Vespel® that can give longer life to metal components. Here are microphotographs of contamination particles and how they interact with a wear surface.

In the top photo, we can see how a contamination particle can affect an aluminum substrate during a wear test. Notice that the particle remains on top of the wear surface and results in groove formation and damage to the surface of the aluminum part.

In the lower photo, under the same test conditions the contamination particle embeds into the Vespel® part and remains below the wear surface. Notice the lack of groove formation – we believe because the particle is no longer in the lubricant film and not able to cause additional damage to the wear surface.

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Now let's see if this observed phenomena can be translated into measurable improvements in wear. Here are test results in which our Japan colleagues established a steady state wear condition using clean oil and three different resin compositions. While the test was running, they introduced contamination particles shown in the photograph.

The solid gray bars show the steady state wear rate with clean oil. The patterned bars show the wear rates after the contamination particles were added.

Vespel® demonstrates a 65% improvement in wear vs PEEK. We believe this is due to the ability of Vespel® to allow particles to embed and not to cause additional damage.

We also believe this can be applied to hot dirty bearing surfaces which are exposed to contamination in exhaust systems or engine compartments. Let's look at some examples.

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First in emission systems, our customers have had success in extending the life of bearing and wear surfaces by using Vespel® parts in EGR and bypass valves, as well as associated components such as control arms and cams.

These are typically dry applications which require not only low friction and high heat resistance, but also consistent friction over the life of the part. Providing consistent friction becomes difficult as contamination such as coke or fuel particulates accumulate within the components or on metal shafts.

Vespel® has been shown to resist these contaminates and provide predictable, consistent performance over the lifetime of the engine.

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Likewise in turbocharger systems, we see similar environmental requirements. In turbos there can be a combination of wet or dry friction situations, both of which operate at high temperatures in the presence of contamination.

On the outside of turbochargers our customers have had success in improving the life and consistent operation of control arms and linkages. Specifically in rod ends and spherical bushings used to precisely control the operation of the turbocharger – shown at the bottom right.

In addition, we see opportunities to improve friction and efficiency inside the turbocharger, in typically lubricated applications like the shaft seal rings or shaft spacers shown at the bottom left.

One thing I have not mentioned about our new SP-2515 is its thermal expansion. It has a thermal expansion rate designed to be very close to aluminum, stainless steel and cast iron. So if you have an application that goes from very cold to very hot, SP-2515 may help you obtain significantly tighter tolerances.

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To wrap up this friction discussion, let me summarize four benefits of controlling friction:

- First there are direct efficiency improvements – simply by reducing friction, energy efficiency is improved.
- Second there is an indirect benefit, especially in fluid control systems. By reducing leak rates and rotating friction, smaller oil pumps can be used – resulting in lower parasitic energy losses.
- Third, the ability of Vespel® parts to run directly against aluminum shafts and housings helps component engineers reduce system mass – especially important for light weighting vehicles and in stop/start applications.
- And finally, we have demonstrated that Vespel® can provide lower total costs by eliminating the need for steel inserts and by simplifying assembly operations. In addition, customers have achieved cost savings by extending the life of components and by reducing or eliminating routine maintenance of parts subject to wear and friction.

At the bottom I've again shown our web site which contains much more information on Vespel® high performance parts and the results I highlighted today – I encourage you to visit the site to view or download more information on controlling friction – or to send us an inquiry.

This concludes my formal remarks for today. I'd like to turn it back over to Lisa to lead us into our question and answer session.

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