Technical

Studying form factor printed electronics in fabrics

By Leonard Allison
Engineered Materials Systems Inc.

Executive summary

Printed electronics using polymer thick film is experiencing incremental commercial growth when printed onto soft, pliable or stretchable substrate. PTF electronics on traditional polyester film has reached higher levels of durability with recent design and material advancements, but is limited at 2D flexing, is not pliable and can be a noisy or noticeable interface.

These material durability advancements on PET film have proven to work on pliable substrate as well. The advantage of pliable electronics over PET film-based electronics is a circuit that can be flexed in 3D for a soft and quiet human-machine or bio-sensor interface.

This paper will describe several ink-substrate combinations for incorporating PTF circuitry onto fabrics, performance levels, ASTM methods being developed and potential applications.

Many applications for printed electronics and sensors require a better interface. This could be a wearable but undetectable biometric sensor or a seat sensor where pliability, comfort and low noise is important.

Printed electronics using polymer thick film materials are proven to apply and

TECHNICAL NOTEBOOK
Edited by John Dick

perform well on a wide range of substrates or transfer inks that make possible new form factor[1] printed electronics. A thoroughly engineered combination of PTF, substrate and process can meet a wide array of performance requirements.

Discussion

Why the problem was not already solved or other solutions are ineffective?

The electronic circuitry market is dominated by etched copper traces and solder. Rigid circuit boards (aka PCB or RCB) and flex circuits (flexible copper circuits on polyimide film) are the common formats. 'Printed Electronics' is the recently accepted term by industry pundits for circuitry made using conductive inks and adhesives (PTF materials).

In short, integrating copper circuitry into a soft or pliable format is not practical.

Why a better solution is worth considering and why is it effective?

Printed PTF Electronics is ideally and uniquely suited for emerging applications in wearables, E-textile and similar new form factor circuitry.

The supply chain for printed PTF electronics (inks, substrates, printers) has developed robust product and manufacturing processes over the last 30-40 years when printed onto relatively flat and predictable PET film, where planarity and registration are critical. As compared to PET film the newer substrates prevent challenges in several ways:

Dimensional stability with heat

• Substrate must survive temperatures required to cure ink with minimal warpage or shrink;

• Ability to transport substrate through printing and drying process; and

• Ability to stack or wind substrate after print/cure process.

Dimensional stability as a print receptor

• Downward squeegee pressure can distort surface and registration; and

• Ink solvent can attack and warp incompatible substrate.

Printable surface of substrate

• Printing directly onto fabric is impractical;

• Surface topography challenges consistent ink deposit, fine line and electrical continuity;

• Some thermoplastic urethane films exude emollients or are not homogeneous; and

• Ink adhesion and ability to stretch, crease, crumple, flex and wash/dry are required

The good news is that many options exist that address these challenges and bring valuable advantages over PET film.

Incorporating printed electronics

Table 2 shows a few broad categories of ink substrate of ink-ink transfer methods that are proven to work well together and process well. New combinations are being discovered and developed every day.

The comment "similar to PET" implies that this feature provides a substrate format that handles much like PET film in the printing process.

Types of inks designed for these electronic applications include:

• Silver conductor;
• Silver:silver chloride sensor;
• Carbon ink resistor;
• Force sensing resistor;
• Dielectric insulator; and
• Moisture resistant encapsulant.

Figs. 1-5 illustrate these methods.

Performance levels of conductive ink

Performance criteria for conductive ink on pliable or stretchable format vary by application, and the applications vary greatly.

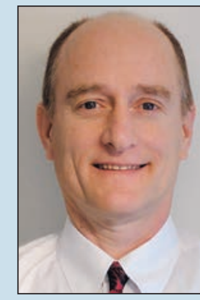
Common requirements include ink adhesion and electrical continuity throughout the following:

• Wash and dry cycles;
• Crease, flex, crumple, compress; and
• One time stretch until electrical open or repeated cycles of x percent.

The wash and dry rating for the Mimo Baby shown in **Fig. 5** is 90 cycles. Performance of the heat transfer inks is > 50 cycles. The wearable market typically

See **Electronics**, *page 18*

The author


Allison

Leonard Allison has more than 30 years of experience in printed electronics design, fabrication and materials, including a 10-year assignment in Asia. He is business manager of printed electronics for Engineered Materials Systems, a division of Nagase Corp.

Allison received a bachelor's degree in mechanical engineering from Michigan State University. He serves on the Printed Electronics and Membrane Switch committee of SGIA, and participates in ASTM and IPC standards development.

Table 1: Electronic circuitry F.A.B.

TYPE	FEATURES	ADVANTAGES	BENEFITS
RIGID CIRCUIT BOARD	Imaged & etched Cu	Fine line, highly conductive, solderable	Dense solid-state packaging with integrated IC chip/battery
COPPER FLEX CIRCUITS	Imaged & etched Cu, some additive printed plating seed	Fine line, highly conductive, solderable, flexible	Flexible and dense with integrated IC chip/battery
PRINTED ELECTRONICS PTF	Printed inks & adhesives, additive process. Conductive particle options	Low cost, environmentally friendly, material function options, wider choices of substrate	Print and integrate circuitry, sensors, components in a wide array of form factors, e.g. biometrics, human-machine interface, etc. IC chip/battery integration requires a Cu circuit hybrid

Table 2: Categories of ink-substrate or ink-ink transfer methods.

TPU film	•Available on heat stable release films - similar to PET •Multi-layer functionality, numerous material options •Heat transfers onto fabrics •Established suppliers, users, processes •Weldability useful for interconnect and sealing
Resin-coated fabrics	•Various material weave, e.g. polyester, nylon, etc •Resin applied to weave to provide printable surface •Various resin compositions •Established suppliers, users, processes
Heat transfer inks	•Plastisol inks common to fabric decoration serve as conductive ink transport mechanism •Established suppliers, users, processes •Compatible mechanical and chemical •EZ to print onto transfer release film - similar to PET

Fig. 1: TPU film heat applied to spandex.

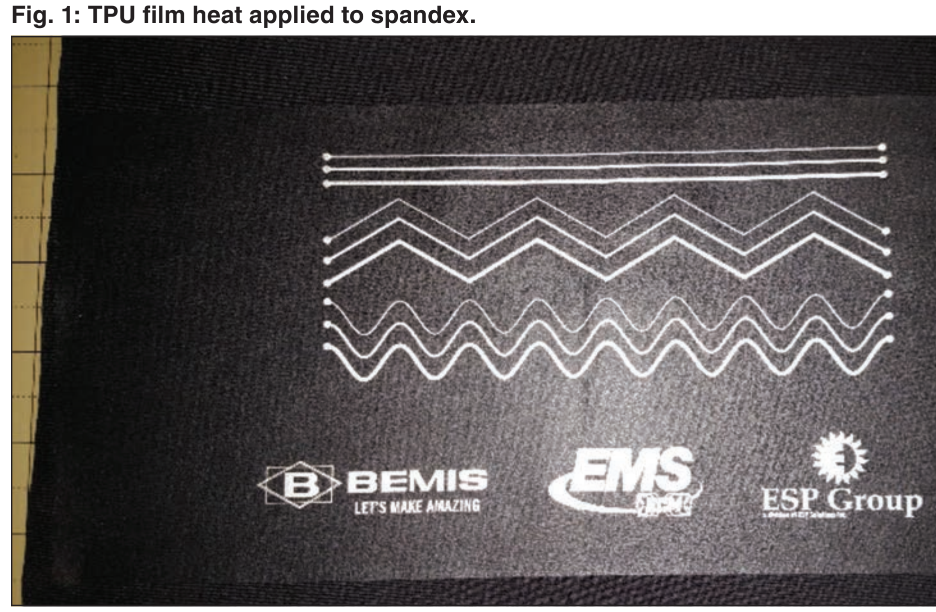
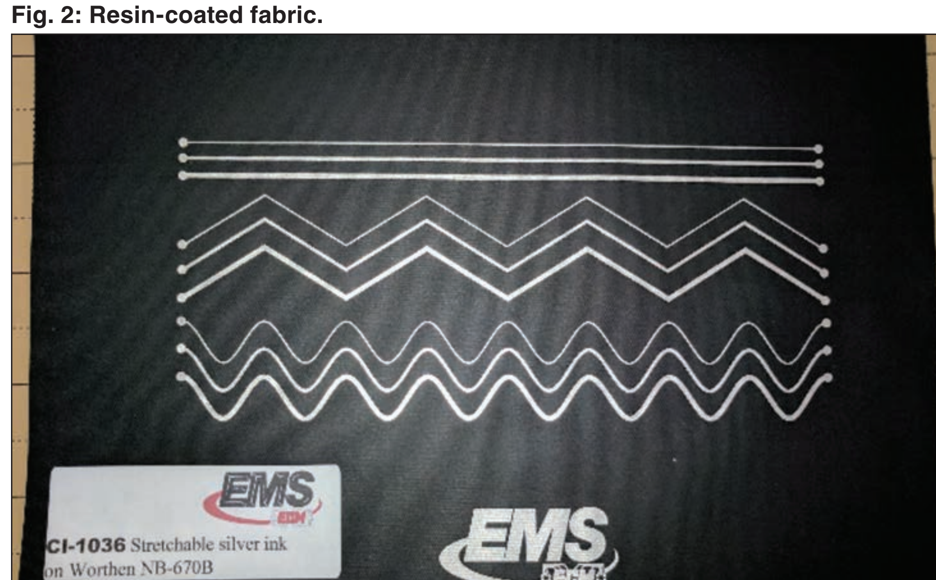


Fig. 2: Resin-coated fabric.



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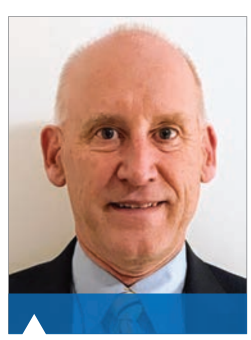

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Electronics

Continued from page 16

requests > 40 wash and dry cycles.

Conductive inks are best served for wash/dry cycling by being insulated with UV-cure insulators or H_2O-based fabric ink. Electrical resistance will increase; the acceptable increase level depends upon the application and functionality requirement.

The inks ability to crease, flex, crumple or compress depends primarily on the ink formulation itself and secondarily on the substrate the ink is applied to.

Assuming that a durable conductive ink is selected, the base film should exhibit either limited elongation or, if elongation is required, good elastic hysteresis or stretch recovery. There are many types of TPU film that can be considered for use with PTF electronics, and performance of the ink/substrate combination can vary.

For example, a mono-layer TPU with excellent stretch recovery and excellent electrical resistance recovery may be too soft for the printing and curing process, and not be heat transferable. A multi-layer TPU that includes valuable layers like a low temp melt (to attach to fabric) and a harder layer for better printability may not have good stretch recovery.

TPU films come in a variety of materials and configurations. Polyester, polyether and polycaprolactone are the three broad categories, and these are further subdivided into aliphatic or aromatic varieties. TPU can be supplied as a standalone mono-layer film, in multi-layers, on release liners, coated onto other films or fabrics, etc.

Each brings varied levels of compatibility with conductive inks and varied ability to meet the requirements of a particular application. The good news is there are many robust and commercially-available solutions.

Not all film candidates need be TPU, although TPU is a versatile film for printed electronics. Strong performers include PVC-coated nylon or polyester weaves, and surely there are others.

The term "stretchable electronics" has become quite popular. While this is a desirable feature and may indicate strength in crease, flex and crumple performance, stretching is the toughest performance requirement for a conductive ink. In a conductive ink, the conductive particles need to be held closely together in a resin binder.

When stretched, the particles will naturally be pulled away from each other and resistance will increase. When applied to a TPU with good elastic recovery the ink will return closely to its original value upon relaxation. Stretchability is significantly improved with a zigzag or sinusoidal pattern but with more ink being used. An example of an application that requires stretch could be a tight-fitting sport shirt with biosensors.

At this early stage of e-textile or new form-factor PTF electronics, it would be best to start with applications that require features such as: soft; supple, pliable; 3D shapeable; durable; quiet when deformed; and comfortable or non-detectable when worn.

Among these features are many potential applications that traditional PET-based electronics will not suffice. In the opinion of the author, stretch performance of more than 50 percent elongation is not practical for this technology for near-term commercial applications but "stretch" will persist as an academic target.

Fig. 3: Stretch feature on TPU film.

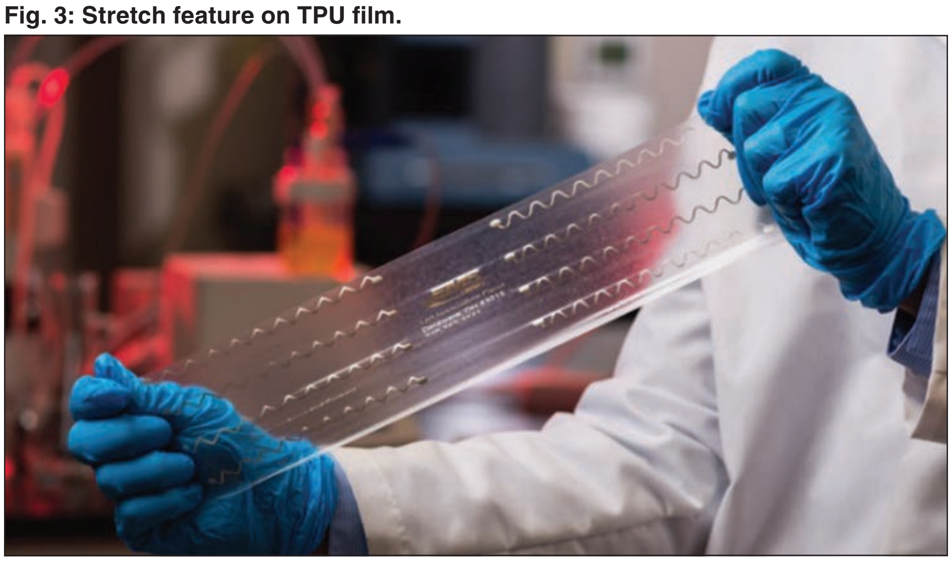


Fig. 4: Heat transfer inks onto fabric.

Fig. 5: Commercial wearable application – Mimo Baby.

Implementation

Pertinent IPC/ASTM standard tests

There are many test standards designed for fabric tests but not necessarily for those that include PTF electronics. Test standards in place for membrane touch switch and printed electronics are geared toward ink on PET film. Fortunately, an IPC committee has been formed to design performance testing specifications for E-textiles.

One draft underway—IPC9204 "Guideline on Flexibility and Stretchability Test Methods for Printed Electronics"—is an important endeavor for this exciting market, and industry participation is encouraged (contact chrisjorgensen@ipc.org).

New means to test printed electronics on soft, pliable, stretchable format are being vetted by industry experts.

Potential applications

Never has there been more interest and developmental activity in this author's 30-plus years of participation in PTF electronics as there is in this new form-factor. Never before has a PTF ink company been able to command an audience with major chip solutions companies.

Many applications are realistic and near term, some not encumbered by regulations or in need of government subsidies as, for example, RFID or solar. Other applications require biocompatibility or FDA and these materials are well suited.

The recent surge in interest may be because of a convergence of several other technologies, material breakthroughs or today's ability to share information quickly. The idea of E-textile has been around for 10-plus years with some IP having come and gone. Recent maturity of chips with multiple functionalities of Bluetooth, sensing, cell phone data logging apps, printed sensors and others certainly has helped.

The following examples are selected to illustrate the wide array of functionality and the value they bring:

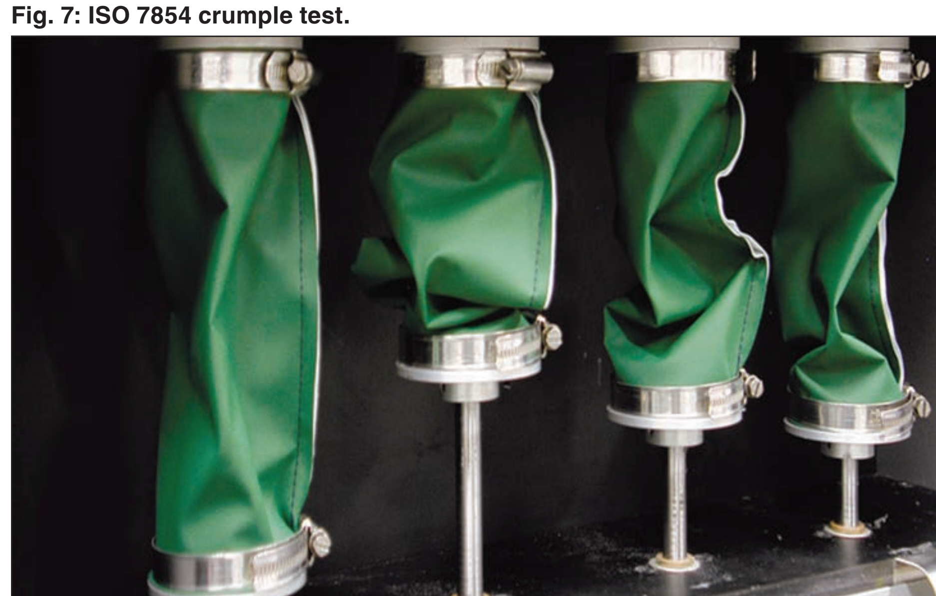
Wearable technology:
- Soft undetectable circuit;
- Limited stretch; and
- Easily integrated IC chip and power module (turtle).

Human-machine interface:
- Soft comfortable interface;
- Quiet when actuated;

See **Electronics**, *page 19*

Fig. 6: ASTM F2749-15 crease test.

Fig. 7: ISO 7854 crumple test.



Electronics

Continued from page 18

• 3D comformable.

Hospital care:

• Durable and biocompatible;

• Biosensing; and

• Remote monitoring, alarms.

Cargo tracking security logistics:

• Soft and durable;

• Undetectable; and

• 3D comformable

Biosensing, therapy, treatment:

• Durable and biocompatible;

• Biosensing; and

• Electronic stimulation, drug delivery, etc.

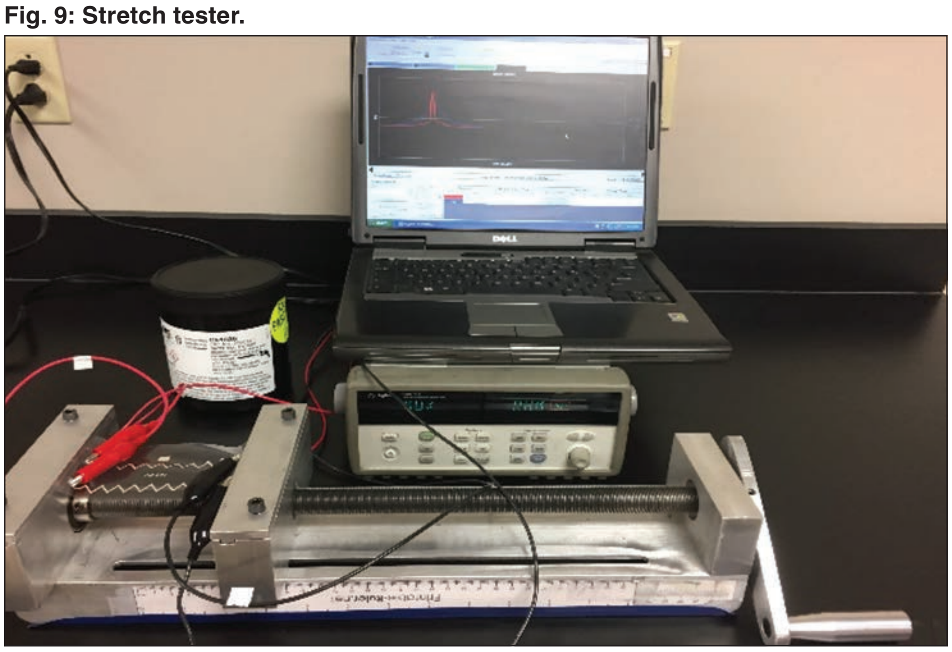
Each of these applications are best served with a different ink-substrate combination. Some stretchable, some just soft, some more durable, some disposable. A "platform" of material and process suppliers are needed to deliver the right solution in the right volume and the right integration of components and interface app.

So the terminology for this field of application needs to be widened. Not all are wearable. Not all are based on fabric (E-textile). Not all are stretchable. Some are a bit of each. But they all require a different and better form factor than that of plastic PET film that brings electronics closer to our everyday lives or business.

Will new form factor printed electronics find its way into the limelight as wearable technology or stretchable electronics has? Maybe not enough sizzle. But it sure has brought a whole new ballgame to polymer thick film circuitry with significant growth potential for the entire industry. And we will all need to work much closer to deliver the required solutions.

Fig. 8: Silver and insulator stretched.

Fig. 9: Stretch tester.



Acknowledgements

Thanks to my EMS colleagues Rich Frentzel, Jay Dorfman, Richard Wells, Alan Brown and Josh Longenbaker for sage advice and long hours of empirical testing.

Thanks to Chris Jorgensen at IPC for perseverance in new test standards development.

Thanks to SGIA for allowing me to submit this article. SGIA has long been a diligent ally to the Printed Electronics and Membrane Touch Switch group.

Thanks to all the substrate material and printing service suppliers who have collaborated with EMS toward material solutions.

Thanks to Rest Devices for your business and for letting us reference Mimo Baby as a commercial application that uses EMS conductive ink.

Reference

1. Wikipedia https://en.wikipedia.org/wiki/Form_factor_(design). "Form factor is an aspect of hardware design which defines and prescribes the size, shape, and other physical specifications of components, particularly in consumer electronics and electronic packaging."

Fig. 10: Silver ink on TPU stretched to 100 percent.

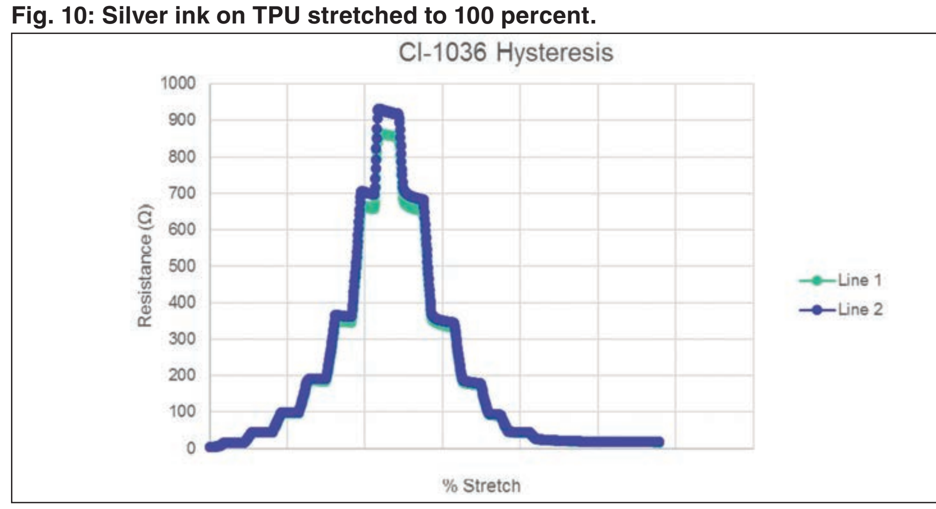
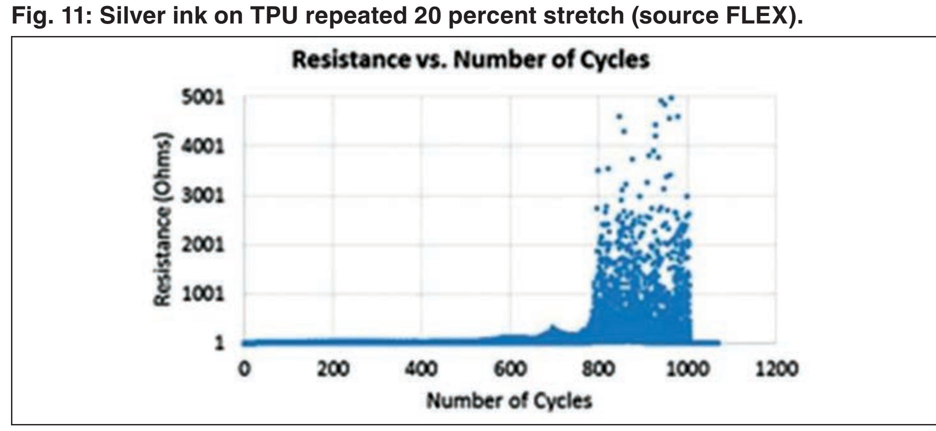


Fig. 11: Silver ink on TPU repeated 20 percent stretch (source FLEX).



Trump

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ers Association, noted the group's long-standing opposition to the steel and aluminum tariffs, because the grade of steel necessary for tire manufacturing is not made in the U.S.

Three suppliers of tire-grade steel have applied to the U.S. Department of Commerce, requesting exemptions from the tariffs, according to Luke.

"Commerce hasn't ruled on those petitions yet," she said. "But they were supported by comments from domestic steel manufacturers, so we're optimistic about those petitions being granted."

As for the tariffs on Chinese goods, these are problematic for tire manufacturers, according to Luke.

"We have a global supply chain," she said. "We advocate for free and fair trade, especially for raw materials, equipment and everything necessary to manufacture tires. Tariffs harm every tire maker that has a facility in the U.S., that is building a facility in the U.S. and that

plans to build a facility in the U.S."

Representatives of auto aftermarket associations expressed the same fears.

"Uncertainty is hanging over everybody's head," said Stuart Gosswein, senior director, federal government affairs, at the Specialty Equipment Market Association. "Nobody had this in their budgets for 2019."

The tariffs on imported steel have affected prices not only on imported steel, but on U.S.-produced steel as well.

"If they're buying domestic steel, there's been a lot of hoarding," he said. "Domestic companies had to raise prices, which had the same effect as tariffs on imported steel."

SEMA strongly supports the Trump administration's efforts to curtail Chinese theft of intellectual property, he said, but the president already has sweeping powers to raise tariffs under current trade law.

For example, Trade Section 232 of the Trade Expansion Act of 1962 allows the president to raise tariffs on or use other means against imported goods he deems to threaten national security. And Section 301 of the Trade Act of 1974 authorizes the president to take action against any act, policy or practice by another country that violates an international trade agreement or that places a burden on U.S. commerce.

A spokeswoman for the Motor & Equipment Manufacturers Association pointed to the filings MEMA made throughout 2018 opposing the Trump administration's tariff programs. In a November 2018 submission to the U.S. Department of Commerce, the association urged the administration to allow greater flexibility on steel and aluminum tariffs and exempt Mexican and Canadian imports from tariffs.

"Often, there are few (steel) producers in the world—in some cases only one or two—that can source the grade of specialty materials needed to make component specifications," the association said. "Examples include wire used in steel-belted radial tires and specialty metals used in fuel injectors."

MEMA, SEMA and the Auto Care Association were among 150 trade associations from a broad range of industries that wrote U.S. Trade Representative Robert Lighthizer in September 2018, opposing the imposition of 10 percent and 25 percent tariffs against goods imported from China.

"Assumptions that U.S. companies can simply move their production out of China are incorrect," the letter stated. "Global supply chains are extremely complex.

"It can take years to find the right partners who can meet the proper criteria and produce products at the scale and cost that is needed," it said. "We do not support the U.S. government using tariffs as a means to induce U.S. companies to change their sourcing strategies."