Development of High-Performance Metalworking Fluids using Sustainable Base Oils:

Straight Oil Formulations

Innovation and sustainability are key values at Biosynthetic Technologies (BT) that drive the strategic direction of the company's development programs. The research team at Biosynthetic Technologies spends most of their time at the interface of these domains, looking for creative ways to solve the world's sustainability challenges.

The operation of metalworking is most simply defined as the process for shaping metal into a part or component. Within the category of metalworking exists two subsets: (1) metal forming and (2) metal removal. Metal forming involves shaping the metal through various deforming actions, including forging, rolling, extrusion, drawing, stamping, swaging, and roll forming. Metal removal, however, involves shaping the metal by removing portions of the metal as chips, including turning, milling, broaching, threading, drilling, tapping, cutoff, grinding, polishing, and lapping.

Just as each of these processes is specific and unique in nature, so are the metalworking fluids designed to complement their service. Metalworking fluids serve various purposes, including cooling, lubricating, reducing wear, corrosion and rust protection, improving surface integrity and finish of the metal, and flushing away chips from the cutting zone. In general, metalworking fluids are either sold as straight oils (also referred to as neat oils) or water-soluble oils (also referred to as emulsifiable oils). They can be further subcategorized into mineral oil, semi-synthetic, and synthetic formulation types.

The purpose of this initiative was to develop two straight oil formulations: (1) a cutting and grinding fluid and (2) a drawing and stamping fluid. For each formulation type, the use of sustainable estolide base oils would be compared to the use of traditional mineral oils.

Cutting and Grinding Fluids

Cutting and grinding is a common type of metalworking application, referring to the literal cutting (with a tool) and grinding (use of an abrasive wheel) to change the shape of a metal. In these applications, as the metal is being shaped by the machine, a metalworking fluid is continually sprayed toward the machine/metal contact point. For applications where heat control is emphasized, water-soluble formulations are typically used, and for applications where lubricity is featured, a straight oil may be used. Cutting and grinding fluids are normally formulated to have lower viscosities to facilitate the flushing of metal pieces away from the work zone.

To compare performance of the different base oils, a pair of cutting and grinding fluids (neat oil type) were formulated with (1) mineral oil and (2) an estolide product. The formulation details are provided below, along with respective viscosity data.

Ingredient	Purpose	Specific Gravity	Mineral Oil Formula (% volume)	Estolide Formula (% volume)
100 SUS Naphthenic Oil	Mineral Base Oil	0.900	90.00	-
BT4 (Estolide)	Biobased Base Oil	0.908	-	90.00
Amine Phosphate	EP & AW	0.910	1.00	1.00
Methyl Stearate	Lubricity Additive	0.870	9.00	9.00
Di-alkyl Polysulfide	EP	0.950	-	-
Viscosities				
40°C, cSt	-	-	16.63	18.75
100°C, cSt	-	-	3.34	4.38
VI	-	-	47	149

Table 1*. Cutting and grinding fluids, formulation, and viscosity data.*

Pin and Vee Performance

Pin & Vee Block testing was performed using a Falex Pin & Vee Block machine. The test works by rotating a 0.25-inch diameter test pin against two vee blocks (each 0.5-inch diameter) that have a specified applied load (200-3000 pounds). During this process, the Pin & Vee block machine can evaluate wear, friction, operating temperatures, torque, and extreme pressure properties in real time.

The Pin & Vee Block test is an ideal method to assess metalworking fluids as parameters like wear and friction can be indicators of tool life, efficiency, and performance during the machining of metal work pieces.

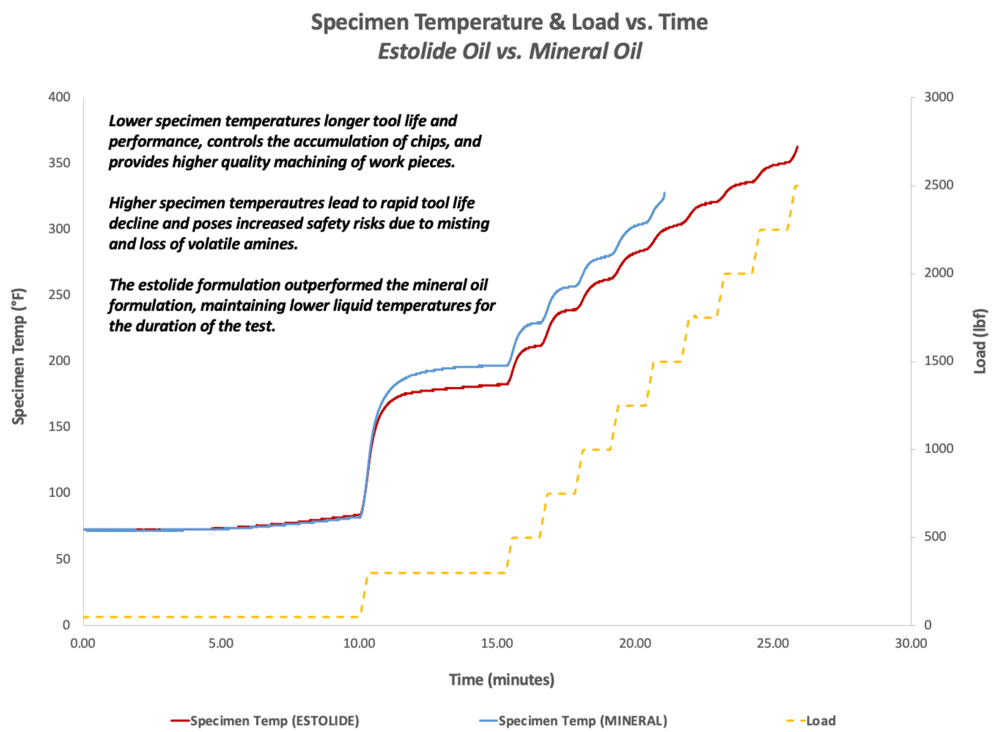

Figure 1*. Pin & Vee temperature data, cutting and grinding fluid. Estolide formulation resulted in lower operating temperatures than the mineral oil.*

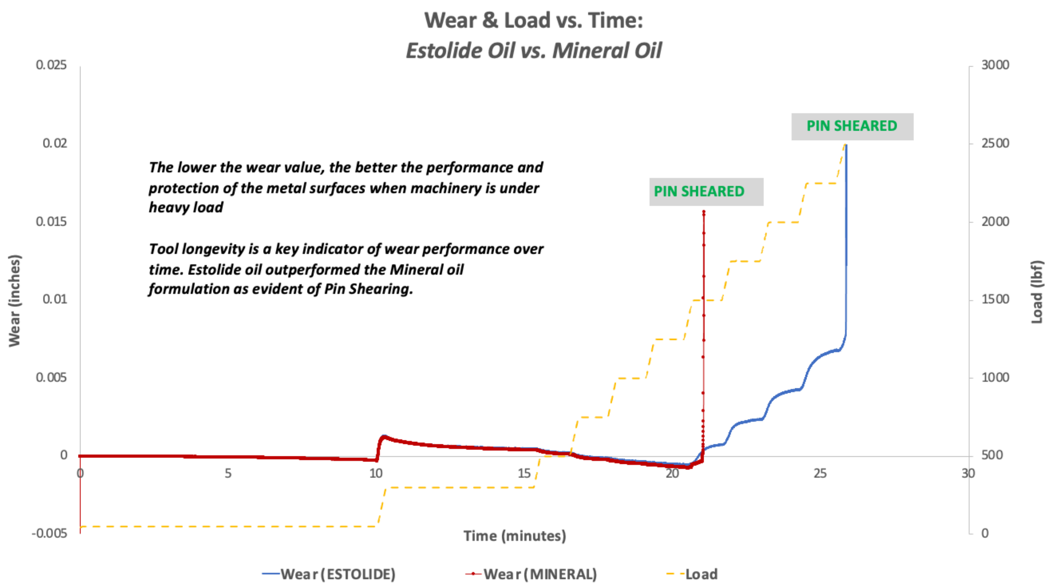

Figure 2. *Pin & Vee wear data, cutting and grinding fluid. Estolide formulation resulted in lower wear values than the mineral oil.*

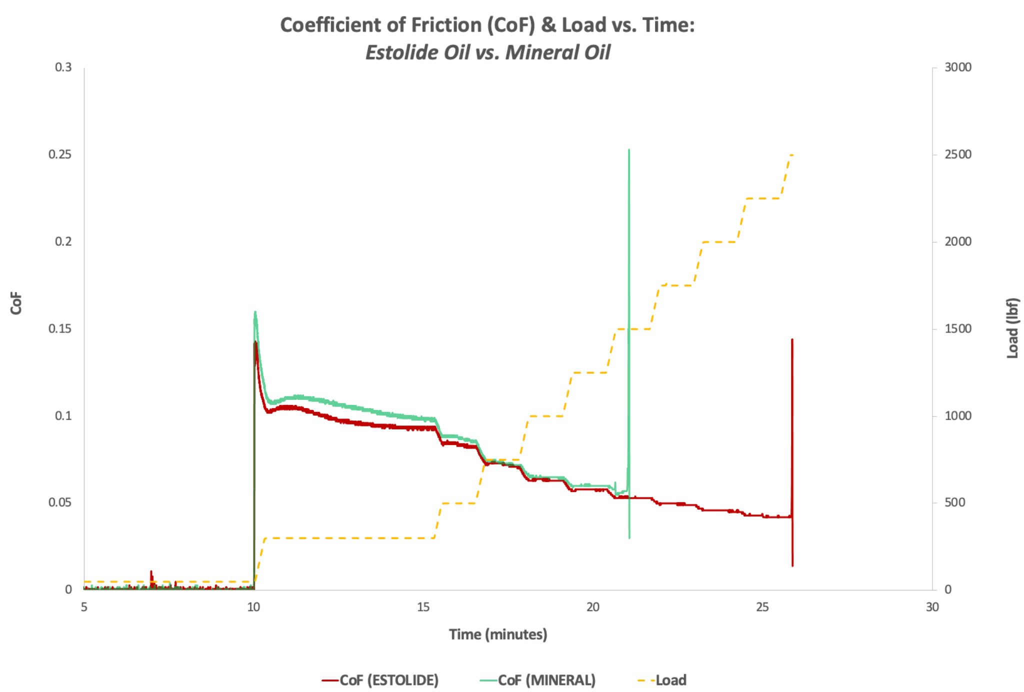

Figure 3. *Pin & Vee coefficient of friction data, cutting and grinding fluid. CoF was slightly lower for the estolide formulation.*

Drawing and Stamping Fluids

Drawing and stamping is another common type of metalworking operation defined as the intentional deformation of metals to achieve desired shapes. The process of drawing, specifically, is the pulling of a metal through a mold or die, such as a perforated block through which metal is drawn or extruded. Stamping, on the other hand, is a process that transforms sheets or coils into specific preset shapes by using tools that bring conformational changes to the metal. To lubricate these types of environments, straight oils are typically used, providing lubrication and cooling for metal bending, stretching, and shaping.

For purposes of comparison, a set of drawing and stamping fluids (neat oil type) were formulated with mineral oil and estolides. The formulation details are provided below, along with respective viscosity data.

Ingredient	Specific Gravity	Mineral Oil Formula (% volume)	Estolide Formula (% volume)
2400 SUS Naphthenic Oil	0.921	50.73	-
200 SUS Naphthenic Oil	0.910	38.27	-
BT22 (Estolide)	0.916	-	89.00
Amine Phosphate	0.910	1.00	1.00
Methyl Stearate	0.870	9.00	9.00
Di-alkyl Polysulfide	0.950	1.00	1.00
Viscosities			
40°C, cSt	-	86.18	101.80
100°C, cSt	-	9.22	16.73
VI	-	77	179

Table 2*. Drawing and stamping fluids, formulation, and viscosity data.*

Twist Compression Test (TCT) Performance

The TCT evaluates friction conditions in metalworking processes such as drawing, stamping, and tube hydroforming. TCT functions by applying a rotating annular tool pressed against an immobile piece of sheet metal, at a selected pressure and sliding velocity, to simulate lubricant performance in the metal forming process.

A pressure transducer measures pressure applied by the annular tool on the sheet metal, while a torque transducer measures the torque transferred from the tool to the metal sheet. The TCT is deemed complete when the first signal spike occurs in the torque/CoF output, indicating failure of the fluid layer boundary (metal-on-metal contact).

The TCT results show that the estolide formulation passed the test, whereas its mineral oil counterpart quickly failed. On a molecular level, it's hypothesized that the polarity and structure of the estolide creates a protective boundary at the metal surface, enhancing the wear protective qualities of the estolide-based formula.

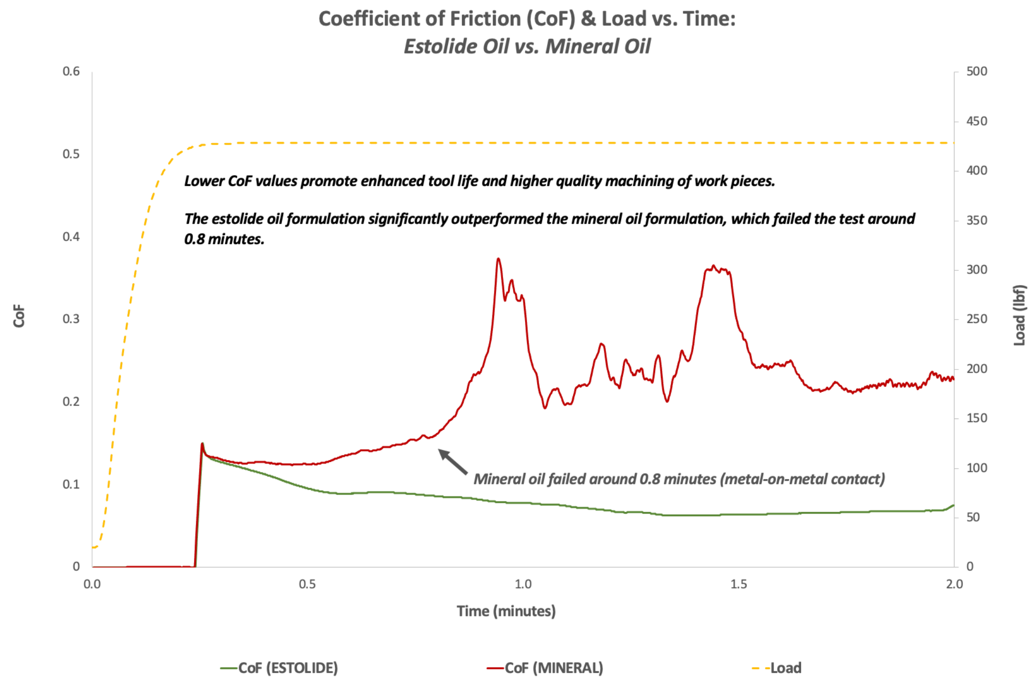

Figure 4. *TCT coefficient of friction data, drawing and stamping fluid. The estolide formulation far outperformed the mineral oil, which failed around 0.8 minutes.*

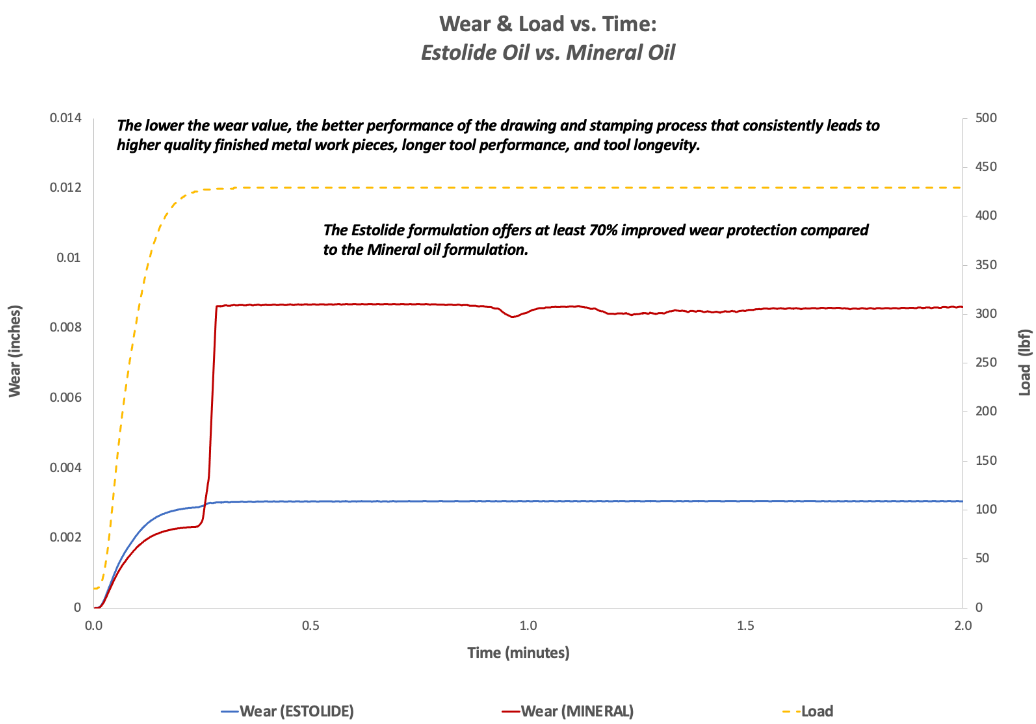

Figure 5. *TCT wear data, drawing and stamping fluid. The estolide formulation outperformed the mineral oil by ~70% reduction in wear.*

Conclusion

While the various combinations and customizations available to a metalworking fluid formulator are vast, BT researchers not only demonstrated that estolides can be suitable alternatives to mineral oils, but they also actually outperform their counterparts in several key areas. Additionally, for product developers seeking to enhance the environmental characteristics of their offerings, estolides are bio-based, biodegradable, non-toxic, and non-bioaccumulative.

If you're interested in commercial opportunities related to manufacturing these products, or any other projects, please contact Matt Kriech at mkriech@biosynthetic.com.