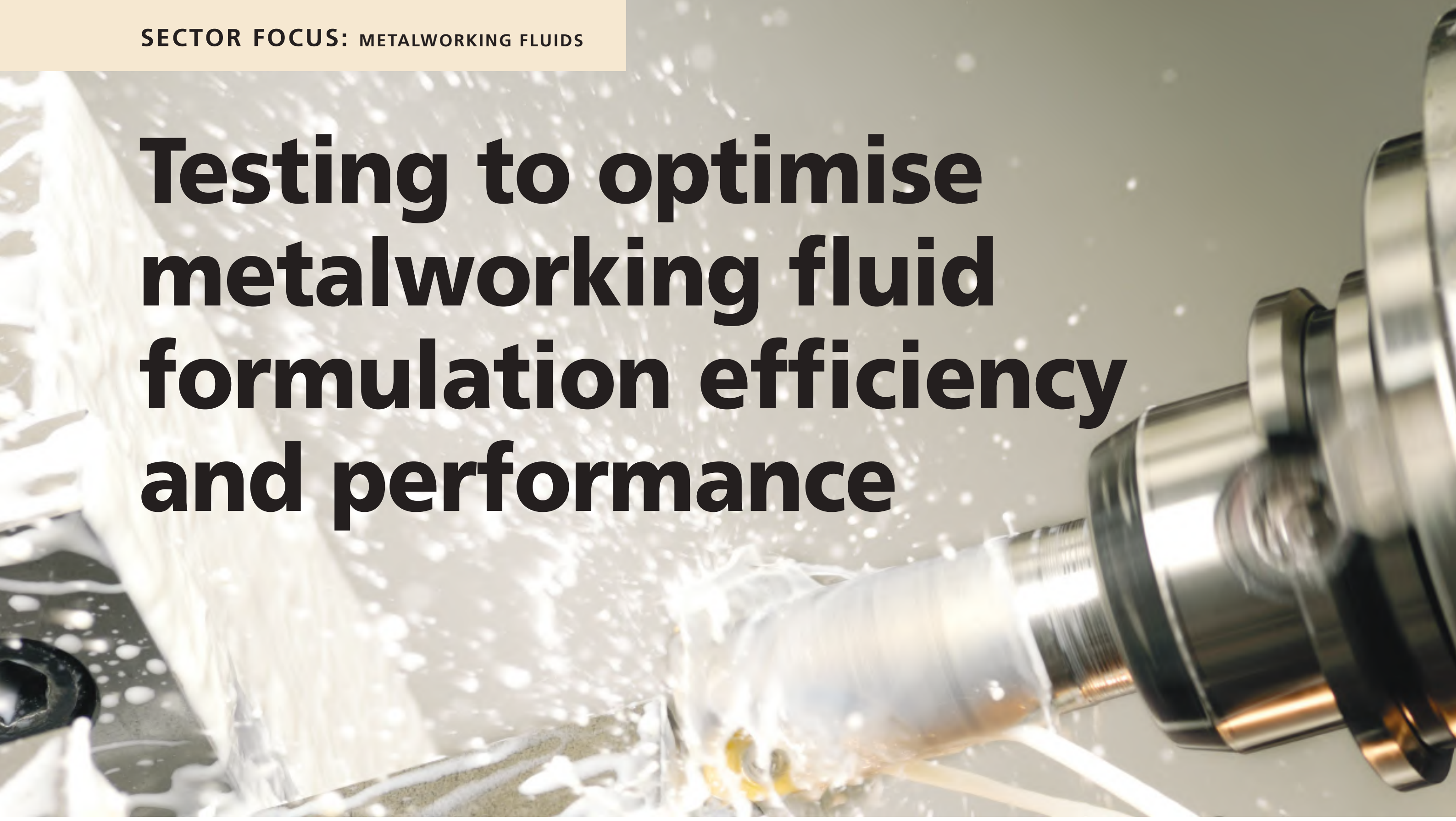

Testing to optimise metalworking fluid formulation efficiency and performance

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One of the outcomes of the automotive industry's continued focus on operational efficiency and technological advancement is a growing trend towards sustainable innovation for lighter vehicle design. This shift has led to an increased demand for more dynamic metalworking fluids (MWFs) that perform well on lighter weight aluminium alloys for vehicle components and new machining tools. Evaluating the relative effectiveness of metalworking additives is critical in the optimisation of a commercial fluid and the development of new formulations. This means systematic, efficient MWF formulation techniques and rapid, flexible test methods that correlate well with field performance, are more important than ever.

An array of American Standard Test Method (ASTM) tests exists to effectively determine additive effects on MWFs, including the twist compression test (TCT) and tapping torque test (TTT). These ASTM methods are designed to evaluate lubricity additives by measuring coefficient of friction (COF) or torque under variable conditions. Pine chemicals manufacturer Ingevity worked with Sea-Land Chemical to provide a comparative analysis using a simple straight-oil MWF to determine the relative performance of multiple lubricity additives per test method and to discover whether a correlation between the two methodologies exists.

As the conditions for each test method vary significantly, it is important to understand the differences and how each can impact the effectiveness of the additive. For example, the TCT operates at extreme pressure, creating specific tribological conditions to determine average and static COF, time to break down, and surface wear. Although the TCT equipment does not mimic any specific machining or metalworking process, it allows for variation of the applied torque and rotational speeds up 35,000 pounds per square inch (psi) and 30 revolutions per minute (rpm). These conditions mean the boundary and mixed lubrication regions of the MWF can be analysed along the Stribeck curve and the amount of lubricant depletion can be measured.

Alternatively, the TTT is a simulation test based on forming or cutting metal taps that determines the torque required to tap a pre-drilled hole with typical speed settings ranging from 1000 to 1500 rpm. Compared to the high-pressure TCT conditions, the TTT operates under low pressure in the hydrodynamic or boundary regions of the Stribeck curve, and the actual point of contact is a bevelled edge. While the TCT commonly evaluates straight oils, the TTT generally tests water-based formulations, such as soluble oil or semi-synthetic MWFs.

Materials and Methods

Parameter	TCT	TTT
Tribotest Type	Bench	Simulation
Test Method	ASTM G02.40: WK24745	ASTM D-5619
Contact	Area: Depleting	Line to Area: Non-Depleting
Speed	1.2 cm/s (10 rpm)	47 cm/s (1500 rpm)
Pressure	55 MPa (800 psi)	NA-14 mm Depth
Substrate	Flat Sheet: AA 6061-T6	AA 6061: Pre-drilled holes
Tool	Annulus: D2 tool steel; R_c~62 Lapped Ra~0.17μm, 207 mm^2	HSS388521/Nitride: Thread formed
Response	Average COF	Average Torque (Nm)
Repeats	3	5

Table 1: *Summary of TTT and TCT results*

The additives selected for this study represent common chemical classifications of lubricity additives, including a vegetable oil (VO), a butyl ester of tall oil fatty acid (BE) and a phosphate ester (PE). Lubricity additives derived from VOs and BEs are made from renewable resources and provide supplemental environmental advantages. The base stock used consisted of a blend of Group I naphthenic oils with two different viscosities in order to maintain a constant viscosity[1]. The TCT and TTT methods were used on the same sample of each blend to minimise variation. A design of experiment (DOE) determined interactions between additives and lubricity optimisation. Each additive was varied from 0-16% with a total 20% additive in each blend. The average response for TTT and TCT was measured for each blend, then tested multiple times so a standard deviation of each measurement could be determined.

Results and Discussion

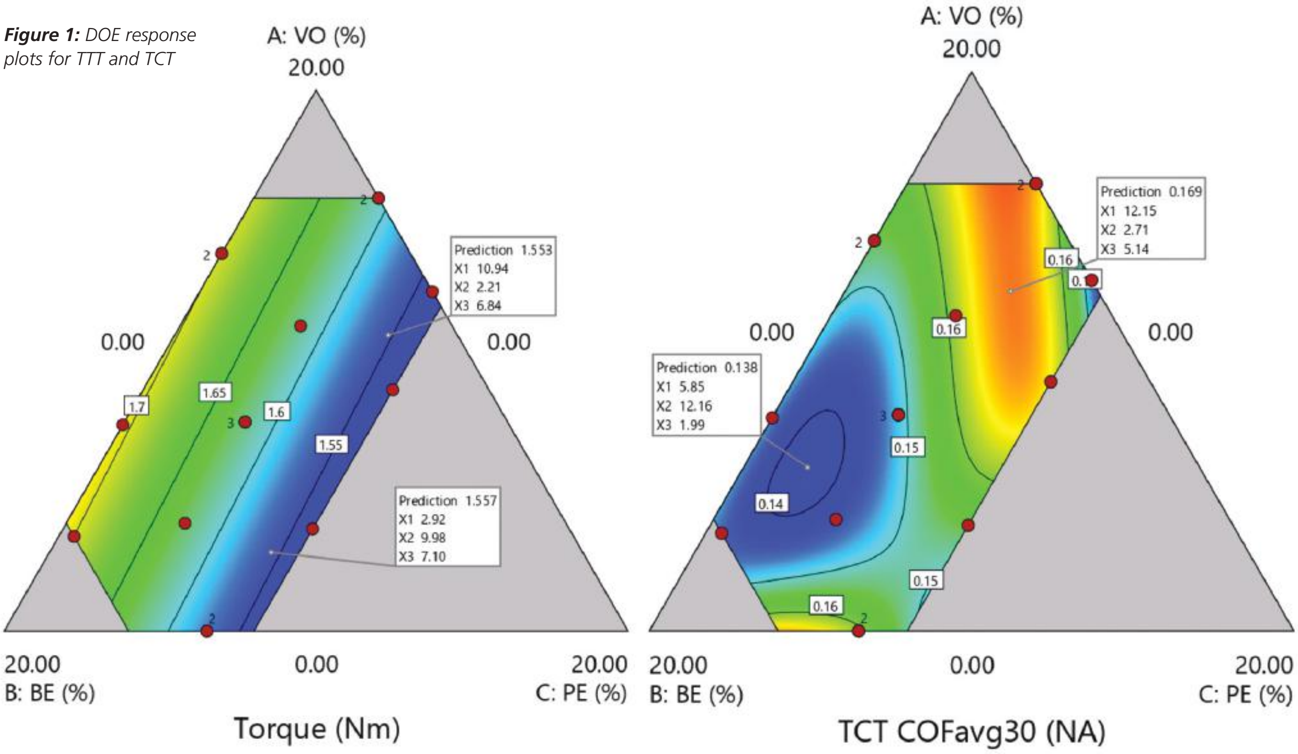
A summary of the results is shown below in Table 2. The differences in the absolute TTT torque (Newton meter) and TCT average COF appear small, but the precision of each test method yields statistically distinct responses.

VO (%)	BE (%)	PE (%)	TTT Torque (Nm)	TTT Std Dev	TCT COF (avg 30)	TCT Std Dev
11.29	4.85	3.86	1.699	0.019	0.151	0.007
0.00	13.50	6.50	1.591	0.005	0.160	0.005
3.99	12.21	3.80	1.598	0.011	0.143	0.004
0.00	13.50	6.50	1.561	0.011	0.163	0.003
7.73	8.41	3.86	1.59	0.004	0.149	0.011
3.78	8.22	8.00	1.546	0.009	0.151	0.006
13.96	6.04	0.00	1.761	0.022	0.151	0.004
8.92	3.08	8.00	1.559	0.006	0.169	0.004
7.73	8.41	3.86	1.594	0.027	0.158	0.008
16.00	0.00	4.00	1.548	0.032	0.172	0.002
7.73	8.41	3.86	1.609	0.029	0.145	0.016
12.55	0.00	7.45	1.555	0.021	0.143	0.002
3.50	16.00	0.50	1.694	0.024	0.142	0.005
16.00	0.00	4.00	1.571	0.016	0.165	0.007
7.63	12.37	0.00	1.71	0.047	0.150	0.006
13.96	6.04	0.00	1.695	0.016	0.156	0.006

Table 2: *Lubricity test conditions and parameter conditions*

The response plots for TTT and TCT are included in Figure 1 below. In both plots, the optimised additive blends are shown in blue and represent the lowest

Figure 1: *DOE response plots for TTT and TCT*



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[1] Interactions with the base oil were not evaluated in this study and could also be a factor in the results. Future tests could be performed with Group II or paraffinic base oils which would have different solubility properties.

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torque for TTT and average COF for TCT. The TTT results clearly show the PE reduces the torque and is the optimal lubricity additive for this test method.

There is little difference in torque for VO or BE in any of the tricomponent blends.

Alternatively, the TCT response plot shows multiple interactions between all three additives. The interaction of the BE and PE is the most significant factor, however, there is no clear trend for any single additive as with the TTT.

The optimised additive composition that gives the lowest predicted average COF was determined to be 5.85% VO, 12.16% BE and 1.99% PE.

Ultimately, this study revealed there is no direct correlation between the TTT and TCT results. These findings show that when designing lubricity additives, knowledge of the end-use application is critical for formulation optimisation.

The TCT results also highlight that the evaluation of a single lubricity additive is insufficient, as the interactions between other additives are essential to reaching the ideal lubricity performance.

The high-precision ability of each test method makes both the TCT and TTT excellent evaluation tools for MWFs.

Formulators today desire lubricity additives that are effective in various applications and fluid types.
By using both the TCT and TTT methods, lubricity additives' performance ranges can be determined, leading to the development of optimal MWFs.

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