ATSP Innovations

Executive Summary

ATSP Innovations and team partner the University of Illinois at Urbana-Champaign (UIUC) have developed a new family of polymers (Aromatic Thermosetting coPolyesters, i.e., ATSP) for application to air-conditioning and refrigeration compressor tribological surfaces. The main advantages of ATSP's polymeric-based coatings are their excellent (superior) wear characteristics, relatively low cost, and simple substrate surface conditioning (i.e., no need for expensive surface preparation before coating).

The impact of this new polymer could also extend into multiple areas and applications such as structural composites in commercial automobiles, low dielectric constant circuit boards for microelectronics, rigid structural foams and ablative material for reentry vehicles. An attractive feature of this technology is the potential for recycling, which is very unique for a thermosetting polymer matrix.

The following are some of the unique advantages of the ATSP system:

- Straightforward synthesis, highly reproducible; resulting in low cost manufacturing process
- Interchain Transesterification Reactions (ITR); which permits repair, attachment of polyester parts to parts with ester units, recyclability of scrap parts
- Liquid crystalline character of ATSP will result in a matching of CTE between the graphite fibers and matrix yielding minimal residual stress in composites and higher fracture toughness, which provides an intrinsic resistance to microcracking
- Designed for high temperatures, ATSP is stable in air up to 350 °C and 425 °C in nitrogen, and with T_g (as high as 285 °C)
- Flammability resistance is far superior to aramides, phenolics and most other systems used as high temperature polymers (LOI: 40%, in presence of graphite fiber LOI is 85%)
    - potential of preparing rigid foams with outstanding flame resistance
- Outstanding wear resistance permits use in most challenging tribological environment
- Excellent adhesion to different metal substrates: cast iron, copper, titanium, stainless steel and aluminum and many other metals.

Table 1 lists some important physical properties of the ATSP resin:

Table 1. Physical properties of cured ATSP resin

	ATSP
Density (g/cm^3)	1.35
Shear Modulus at 25 °C (GPa)	1.2
Glass Transition (°C)	224-275
Long Term Thermal Stability (°C)	
In Nitrogen	425
In Air	350
Char Yield (wt %)	38
Moisture Pickup	0.3
Dielectric Constant	4.6

Preparation of ATSP Coatings

ATSP can be synthesized as a soluble two-part oligomeric system, one consisting of carboxylic acid end groups and the other consisting of acetoxy end groups, as shown in Fig. 1. The coatings can then be applied through a versatile range of techniques including solvent-borne, thermal, and electrospray methods.

The spray coating technique has been used to yield high quality, commercial grade coatings with excellent thickness uniformity, smoothness, adhesion, and tribological properties (see Fig. 2).

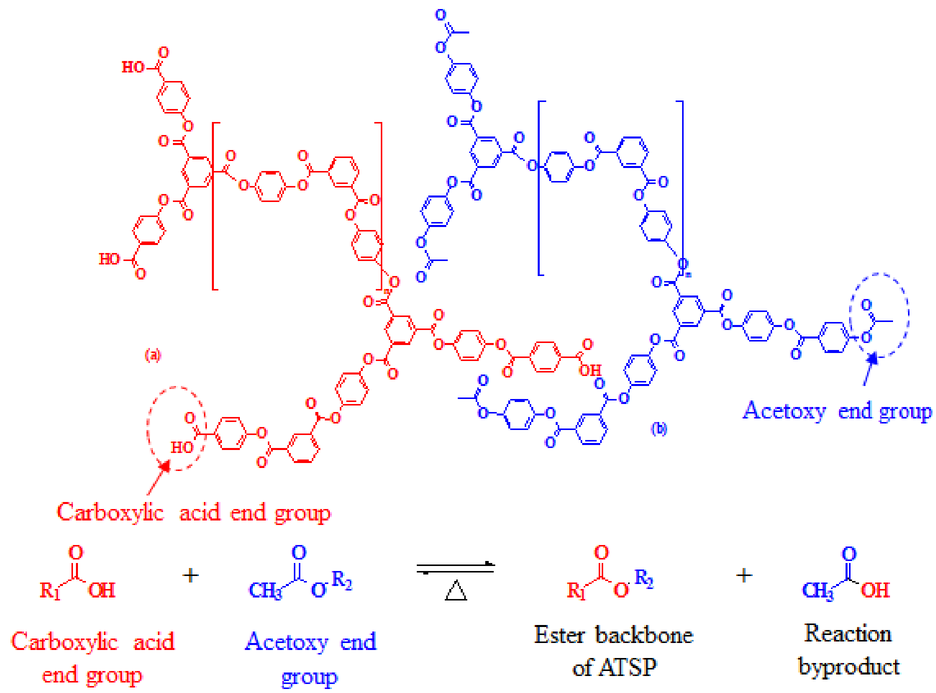

Fig. 1. Chemical structure of ATSP resin

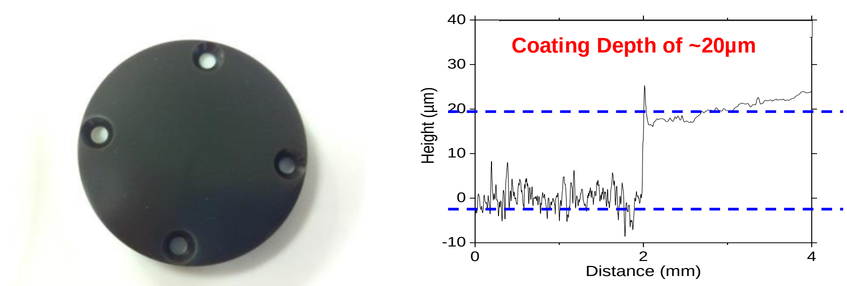

Fig. 2. (Left) A representative spray coated disk. (Right) Profilometry scan indicating coating thickness (which is consistent at 20-40 ± 5 microns)

The polymer can be cured in vacuum at 330 °C or in air at 270 °C. This technique was found to be functionally insensitive to both inorganic and PTFE additives concentration.

Tribological testing for coating characterization

Polymers with better elastic recovery display better frictional behavior due the smaller real contact area. To characterize the elastic recovery of ATSP, coatings on cast iron substrates were tested in a Hysitron TI-950 Triboindenter. Figure 3A illustrate total plastic versus elastic deformation at a maximum load of 15 mN, Figure 3B illustrates percent elastic recovery as a function of maximum load; and Figure 3C illustrates the COF during this process. ATSP coatings demonstrated an almost complete elastic recovery when compared to other commercially available polymeric coatings while still retaining a low and stable COF. This is a quick test that can be used to evaluate coatings and predict whether it is worthwhile to carry out a full set of friction experiments. A nearly complete elastic recovery by ATSP-based coatings indicates that the scratch resistance of these coatings makes them ideal for demanding applications and extends the functional lifetime of these coatings beyond the state of the art.

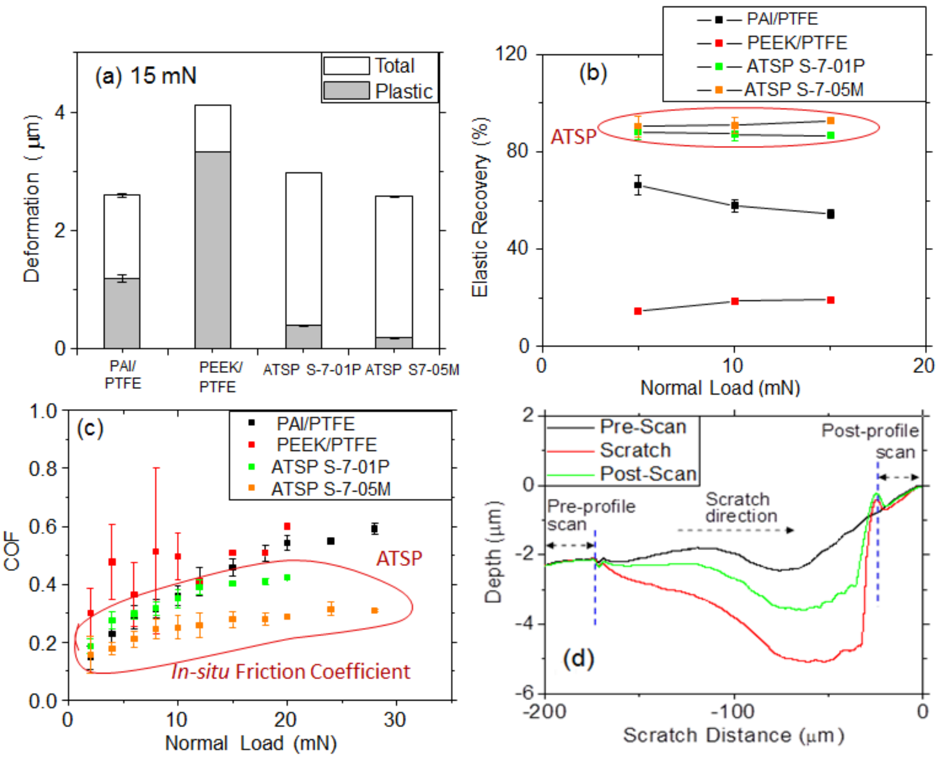

Fig. 3: Elastic versus plastic deformation for PTFE-, PEEK-, and ATSP-coated cast-iron disks.

ATSP-based coatings in scratch experiments carried to normal loads of 80 mN while maintaining the above translation and ramp parameters, as illustrated in Figure 4, evidenced a clear regime below a certain critical force wherein nearly complete elastic recovery is observed.

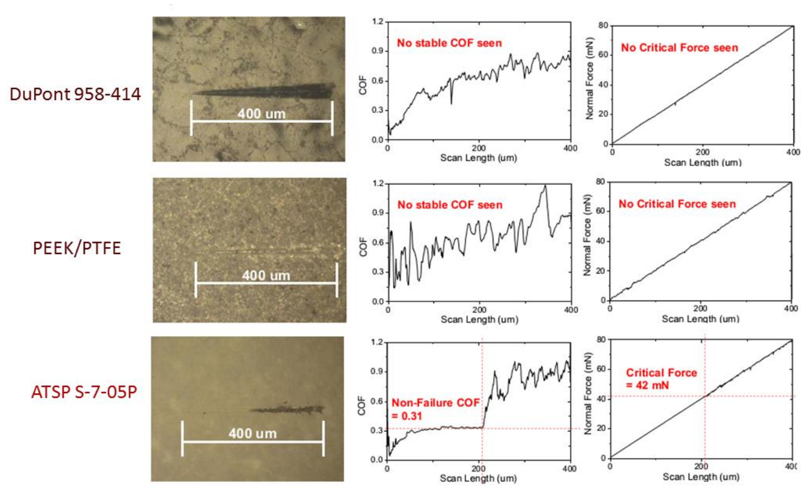

Fig. 4: Results of scratch experiments conducted on PTFE-, PEEK-, and ATSP-coated cast-iron disks.

The spray coated substrates were testing by using the High Pressure Tribometer (HPT) under two wear conditions that simulate an aggressive scroll air-conditioning compressor (summarized in Table 2):

(I) unidirectional high speed sliding conditions, typical of the scroll contact, and

(II) small oscillation fretting motions, simulating the thrust bearing in the compressor.

In both cases, constant load wear type experiments were performed to determine the wear rate and coefficient of friction (COF). The grade of the PAG was Idemitsu NS-D1 (viscosity 300 SUS at 40 °C), and about 46mg of lubricant was directly applied on the interface to develop boundary conditions.

Table 2. Experimental tribological conditions simulating aggressive compressor conditions.

Parameters	Unidirectional	Oscillatory
Normal Load	445 N	445 N
Rotational speed	1500 rpm (3.6 m/s)	-
Amplitude	-	60°
Frequency	-	4.5 Hz
Lubricant	Dry and PAG	Dry and PAG
Viscosity of Lubricant	300 SUS	300 SUS
Operating Temperature	90 °C	90 °C
Refrigerant	HFO-1234yf	HFO-1234yf
Chamber Pressure	0.3 MPa	0.3 MPa
Duration	30 min	30 min

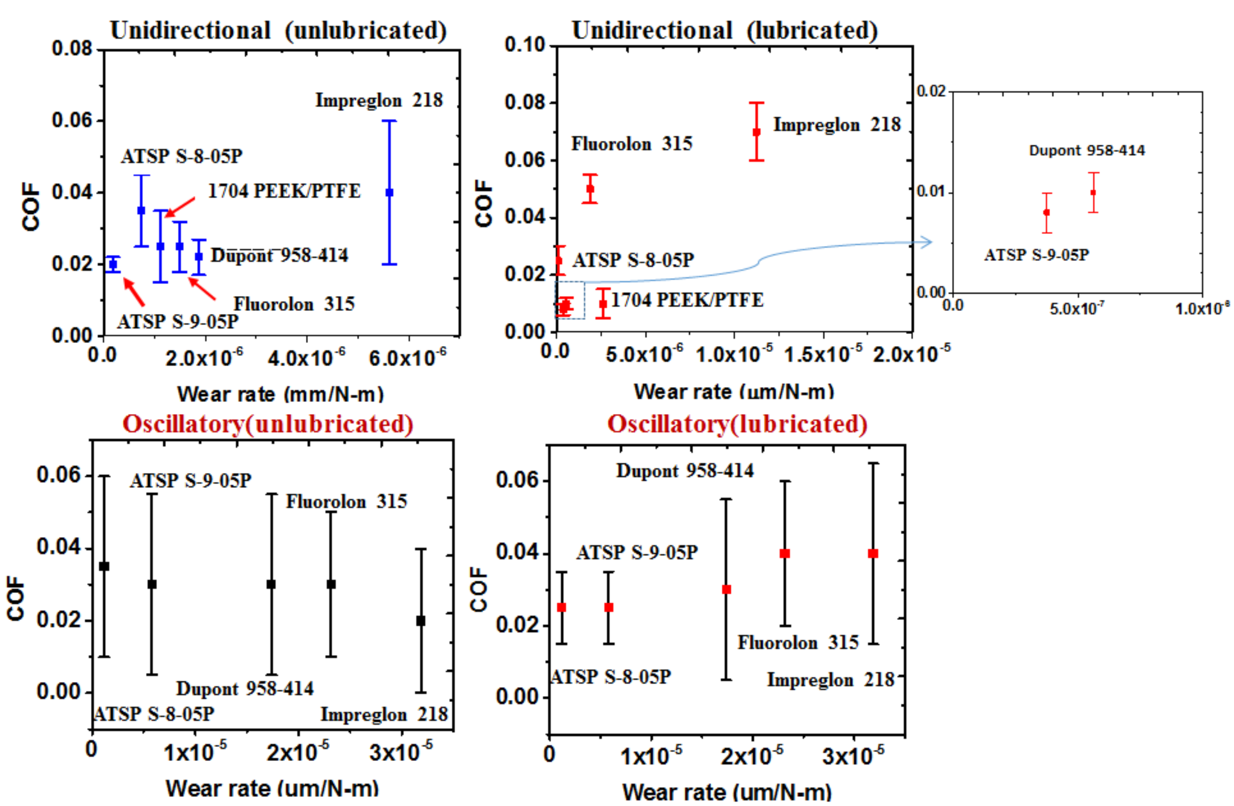

Fig. 5. Friction coefficient (x-axis) vs. wear rate (y-axis) of ATSP versus several commercial polymeric

ATSP-based polymeric coatings exhibited superior tribological performance compared to the state-of-art coatings (used in this study). Morphological analysis revealed better surface integrity for ATSP- based coatings under both unidirectional and oscillatory conditions. Better synergistic effect was achieved for ATSP-based coatings. Specifically, ATSP S-9-05P offered about 30% improvement of tribological performance over state-of-art coatings.