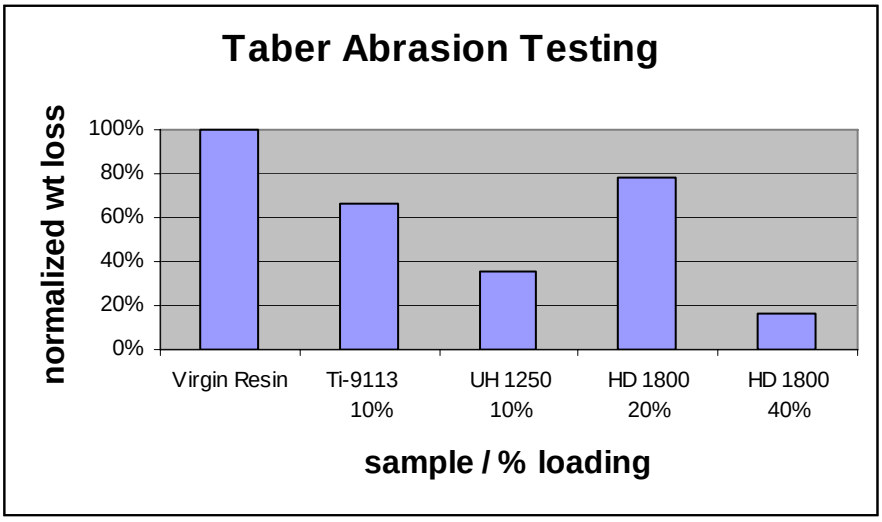
BENEFITS FOR PAINTS & COATINGS

- Increased abrasion and mar resistance
- Increased scrub resistance of paints
- Greater adhesion to substrates
- Lower coefficient of friction
- Profile for slip resistance
- Reduced gloss

Greater Abrasion Resistance

Probably the major reason that INHANCE™ particles are incorporated in formulations is to increase abrasion resistance. UHMW PE has the highest sliding abrasion resistance of all polymers[i]. Incorporation of INHANCE™ UHMW PE particles in epoxy formulations generally increases the abrasion resistance significantly. Data summarizing some Taber abrasion testing, Figure VII, shows that incorporation of 10% INHANCE™ UH-1250 in an epoxy gives abrasion resistance 300% that of the unfilled resin. Use of other INHANCE™ products also improves abrasion resistance.

Figure VII



Adhesion to Substrates

Incorporation of INHANCE™ particles in cast PU and other formulations has been found to significantly increase adhesion to substrates. An example of where this is beneficial is when a PU wheel is molded to a metal hub for the bearing or bushing. Excellent adhesion between the hub and the PU is necessary. The current method for optimizing the PU-metal bond is to prime the metal surface with an adhesion promoter. This is an added step whereby the metal is coated and dried prior to casting the PU. Incorporation of INHANCE™ particles gives better adhesion to substrates with or without use of primers. In fact, some data shows that incorporation of INHANCE™ particles in cast PU gives better adhesion than does use of primer alone. Incorporation of INHANCE™ particles in addition to using a primer give even greater bond strength. Results from one such study are summarized in Figure XII.

Figure XII

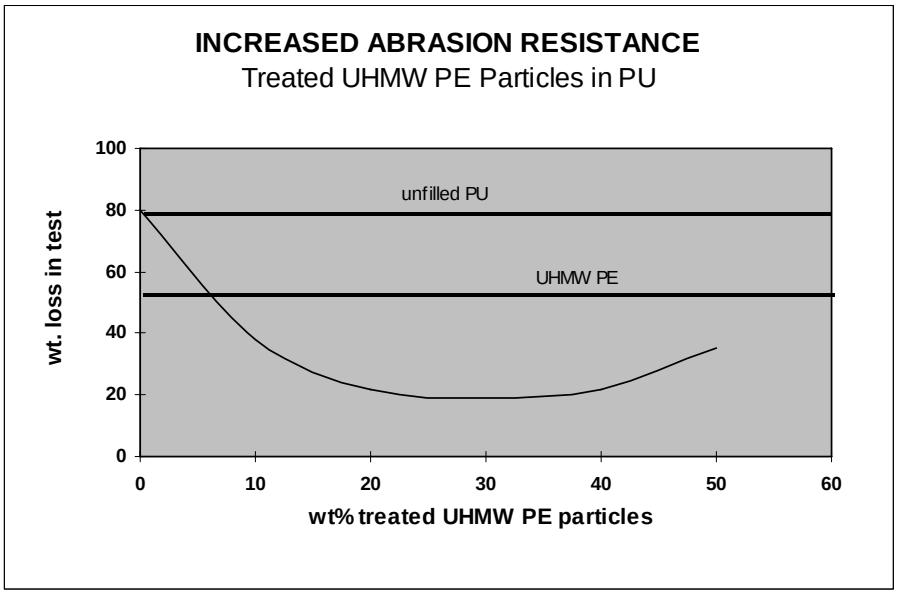
T-PEEL ADHESION TEST: PU BONDED TO STEEL

Additive	Primed?	Bond Strength (lb/in)
None	No	8
INHANCE™ UH-1250	Yes	14
None	No	18
INHANCE™ UH-1250	Yes	24

Abrasion Resistance from Surface-Modified UHMWPE Particles

It should be no surprise that incorporation of UHMW PE particles in polyurethane increases the sliding abrasion resistance. UHMW PE is known to have the greatest abrasion resistance of all polymers. However, the amount of increase in PU composite abrasion resistance is much more than would be expected. Figure IX shows the abrasion resistance of a polyurethane (TDI/polyether prepolymer cured with MBOCA) as a function of loading levels of INHANCE™ UH-1250 particles as determined by the DIN 53516 method. It is noteworthy that not only does the abrasion resistance improve as more UHMW PE particles are added, but beyond 5% addition level, the **PU/UHMW PE polymer-polymer composites outperform even UHMW PE itself**.

Figure IX



Tribologists' explanation for this unexpected behavior is that the polymer-polymer composite has a wear failure mechanism that is different from that of UHMW PE. When UHMW PE sheeting wears, microscopic pieces of material are chipped off. When polymer-polymer composites, consisting of INHANCE™ UHMW PE particles in PU, are exposed to sliding abrasion, the UHMW PE particles deflect into the elastomeric PU matrix and some of the energy is absorbed.

Abrasion Resistance from Surface-Modified HDPE Particles

In the past, there was market demand for smaller particle size surface-modified UHMW PE particles that can be processed on existing meter-mix casting equipment. The closest that we could come was fine particle size (18μ) high density polyethylene (HDPE) particles. Since HDPE sheeting is known to have only about 5 - 10% of the abrasion resistance of UHMW PE sheeting in numerous abrasion tests, it was expected that surface-modified HDPE particles would give little or no improvements in polyurethane formulations, in comparison to surface-modified UHMW PE particles. Nevertheless, this material was surface-modified and evaluated in cast PU.

Unexpected results were again obtained. Surface-modified HDPE particles (INHANCE™ HD-1800) in cast polyurethane formulations are virtually as good as surface-modified UHMW PE (INHANCE™ UH-1700) for increasing sliding abrasion resistance. These results are summarized in Figure X. In addition to being very fine particle size, HDPE particles are considerably less expensive than are fine UHMW PE particles. This is an important development, which opens opportunities for surface-modified polyethylene particles in high volume cast polyurethane as well as various coatings markets.
Since the mid '90's surface-modified 18μ HDPE particles have been commercially available. Today this product is being used in a broad spectrum of cast PU and coatings applications. One customer, who molds cast polyurethane parts, reports that **use of**

INHANCE™ HD1800 surface-modified HDPE particles increases the durability of a specific part fifteen times (15x) longer than parts made in the same polyurethane but without the HD-1800.

Figure X

ABRASION RESISTANCE of UHMW PE VERSUS HDPE PARTICLES

Particles in Cast PU[(a)]	NBS Abrasion Results[(b)]
None	213
25% INHANCE™ UH-1700 (35μ UHMW PE)	783
25% INHANCE™ HD-1800 (18μ HDPE)	746

(a) PPT 95A/Ethacure
(b) Larger value indicates greater abrasion resistance

Stronger Paint Adhesion

Several customers report that incorporation of surface-modified polymer particles in cast PU (and other systems) improves subsequent paint adhesion to molded parts. In fact, one customer was able to stop using primer on the cured PU prior to painting by using INHANCE™ particles in his formulation.

While it is probable that this phenomenon is related to the enhanced adhesion to substrates discussed above, the mechanism has not been determined. One postulate is that surface-modified particles near the surface alter the *interphase* continuous phase polymer around them and extending to the surface, and that the altered chain orientation is favorable for adhesion.

Enhanced Barrier Properties

There have been several reports of increased barrier properties from incorporation of surface-modified polyethylene particles in cast polyurethanes. For example, a manufacturer of industrial coatings reported that in salt spray tests, PU coatings with INHANCE™ UH particles gave greater corrosion resistance than they had ever seen before with a PU. Another example is that PU roll coats made with INHANCE™ polyethylene particles are considerably more resistant to delamination from the metal core via corrosive disbondment than is unfilled PU.

It is expected that barrier performance would be improved because of the “tortuous path” imposed by the particles, a well-know mechanism for increasing barrier properties. However, in these examples the corrosion resistance is greater than can be achieved with other “tortuous path” additives. It has been postulated that increased performance is a result of chloride ions, as they permeate through the PU, preferably associating with the functionalized surface of the INHANCE™ particles. This has the effect of reducing the concentration of chloride ions transiting the PU for some amount of time.

Reduced Solvent Swell

Incorporation of surface-modified polyethylene particles in polyurethane decreases solvent swell. This probably happens because a fraction of the material consists of

polymer (UHMW PW or HDPE) that does not swell to an appreciable amount with solvents. Nevertheless, achieving this reduction in swell, along with enhancing other properties, is important in some applications. Examples of this phenomenon are summarized in Figure XIII.

Figure XIII

REDUCTION IN SOLVENT SWELL for PU[(a)]
ASTM D 471 (25ºC/48 hrs)
Volume % Increase

Solvent	**unfilled**	**15% INHANCE™ UH-1080**
Water	4.1	2.3
Methanol	46.9	35
Trichloroethylene	149	106
Toluene	150	107
Acetone	67	50

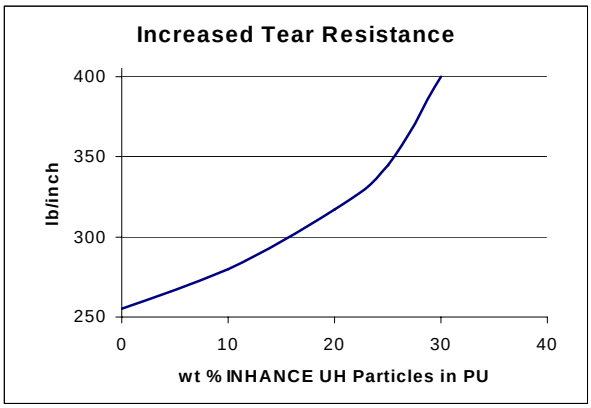
(a)Polyurethane is Airthane® PET 90A/Ethacure® 300

Tear Resistance and Cut Resistance

Incorporation of surface-modified polymer particles in cast polyurethane (PU) increases the tear resistance of these elastomers. Data illustrating this improvement is shown in Figure XIV. This is an important benefit because tearing is a major failure mechanism for PU elastomers. It is hypothesized that the increase in tear resistance is caused by the firmly bonded polyethylene particles "pinning" tears.

Although we have no specific data on cut resistance, it is clear from cutting samples that it is much more difficult to cut PU that contains surface-modified polyethylene or titanium carbide polymer alloy particles.

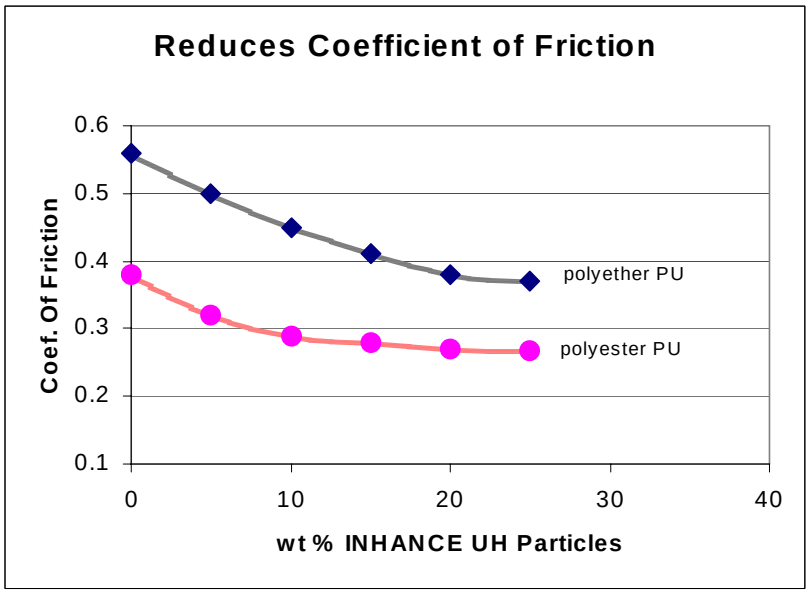
Figure XIV



Reduced Coefficient of Friction

Incorporation of INHANCE™ UHMW PE or HDPE particles in cast polyurethane gives reduced coefficient of friction. This is illustrated in Figure XV. In order to appreciate this effect, the molded part must be sanded or otherwise abraded sufficiently to expose the polyethylene particles. Cast polyurethane parts with reduced coefficient of friction surfaces are desirable for moving parts, like bushings and gears, and for material handling applications.

Figure XV



Latex Paint / Coatings

Paints and coatings are large markets for surface-modified polymer particles. INHANCE™ particles are used in paints and coatings because of the properties they enhance, which include increased abrasion/scrub resistance, greater mar resistance, stronger adhesion to substrates, reduced coefficient of friction, and gloss reduction. The polar surfaces on INHANCE™ particles allows these materials to easily disperse in aqueous latex systems.

Upgrading the performance of latex coatings with INHANCE™ particles sometimes enables these systems to equal or even exceed the performance of two-part (epoxy, polyurethane) and solvent-based coatings. Once target performance levels are achieved, it is almost always desirable to use latex because of ease of application and avoidance of solvents and hazardous chemicals.

INHANCE™ polyethylene particles are used in latex paint formulations to improve abrasion resistance, mar resistance, and scrub resistance. Data in Figure XIII, developed by an outside laboratory, illustrates the increase in scrub resistance.

Figure XIII

LATEX PAINT SCRUB RESISTANCE

ASTM Test Method D 2486

INHANCE™ content →	none	10% HD-1800	10% UH-1250
Cycles until breakthrough	110	160	385

Surface-modified polymer particles are also used in paints and coatings to impart profile for slip-resistance. These particles are used in a broad range of polymer types, including latex, polyurethane, polyurea, and epoxy. The particles are either included with other ingredients in the formulation or they are broadcast after the coating has been applied.

BIOGRAPHY -- BERNARD D. BAUMAN

Bernard D. Bauman is Vice President Special Projects and Vice President & General Manager of the INHANCE business area at Fluoro-Seal, in Houston Texas. Since joining Fluoro-Seal in July 2000, he has been establishing the INHANCE line of surface-modified polymer particles and fibers. Prior to this, Dr. Bauman was Chairman of Composite Particles, Inc., a company that he founded and managed for 7 years. Those products were sold under the VISTAMER® trademark. Although Composite Particles has ceased operations, Dr. Bauman is actively licensing the company's technology for surface-modification of rubber particles. Composite Particles' business, the manufacture

and sale of advanced materials consisting of surface-modified polymer particles and fibers, and titanium carbide polymer alloys was partially based on technology acquired from Air Products and Chemicals, Inc.

For the 17 years prior to founding Composite Particles, Dr. Bauman had been with Air Products and Chemicals, Inc. His assignments there included research and development, marketing, and venture business management. Bauman is an inventor on over 20 U.S. patents. He conceived the technical foundation of surface-modified polymer particles in the early 1980's. This technology was developed, scaled-up, and introduced to the marketplace by Bauman's group at Air Products over a 12-year period. Prior to Air Products, Bauman was with the Rohm and Haas Company for 2 years, in the Pioneer Research Department.

Bauman's education includes a BS in Chemistry from Eastern Nazarene College, a Ph.D. in Physical Organic Chemistry from the State University of New York at Albany, and a postdoctoral scholarship at the Pennsylvania State University.