Performance Advantages of Ketoprix™ Polyketone Resins in Flexible Film Packaging

Due to its high permeation resistance, unique balance of strength and ductility along with excellent chemical and sterilization resistance, Ketoprix™ polyketone resins offer film producers a cost effective alternative to other thermoplastics commonly used to produce flexible packaging. Moreover, Esprix Technologies has developed a proprietary tie layer resin technology which will allow the flexible packaging community to use Ketoprix™ resins to tailor the properties of their multi-layer structures to achieve previously unattainable combinations of mechanical and economic performance!

Films produced from Ketoprix™ polyketone resin exhibits high permeability resistance to many gases as well as low moisture vapor transport properties. Moreover, the permeability of Ketoprix™ is not sensitive to ambient moisture (relative humidity) levels as is the case with some other thermoplastics commonly used in flexible packaging films. For example, oxygen permeability of EVOH (32% mol PE content) increases from approximately 0.2 at 65% RH to 2.0 cc-mil/100 in^2 - 24 hr-atm at 90% RH. As can be seen in the Table 1 below, the oxygen permeability of Ketoprix™ polyketone resins exhibit an oxygen transmission rate similar to EVOH in high humidity conditions and somewhat better than that of polyamide films.

Table 1. OTR rates for 4 mil thick Ketoprix™, EVOH and Polyamide Films

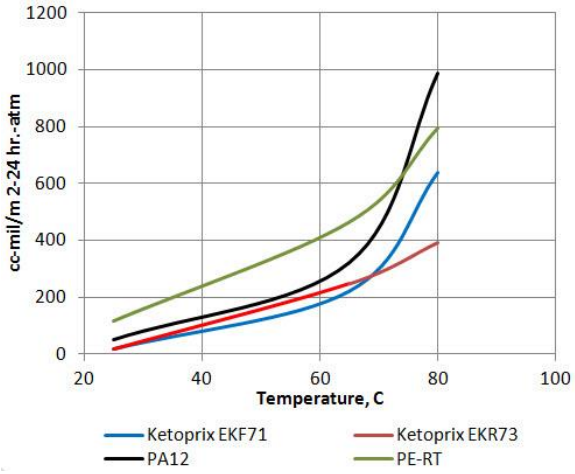
Resin	OTR cc-mil/100 in^2-day-atm 65% RH
EK61[1]	1.75
EKF62[1]	1.65
EKF63[1]	1.42
EVOH[2]	0.2
PA6 (oriented)	2.5-3.0

1. Unoriented film
2. 32% mol PE content grade

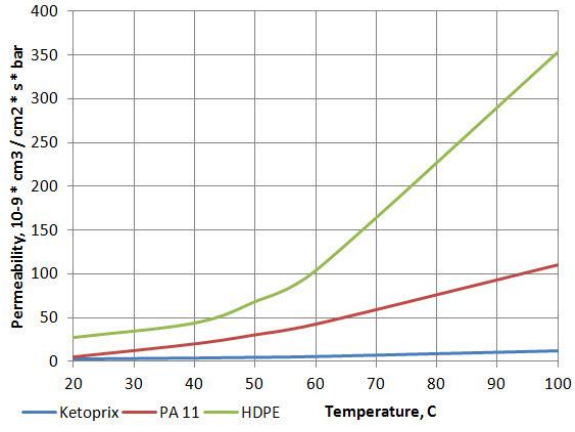
It should be noted here that being drawn, or oriented, during the film production process is known to decrease permeability (improve) with crystalline resins. Considering that the Ketoprix™ films used to generate these data were not oriented, these values do not represent the best possible results achievable with Ketoprix™ resins.

Depending upon the intended end use application, a materials' permeation resistance to other common gases can be important as well. Permeation resistance to hydrogen, carbon monoxide and methane gases are of particular interest. As can be seen from the graphs below, films produced from Ketoprix™ polyketone resins also offer excellent performance in this regard as well.

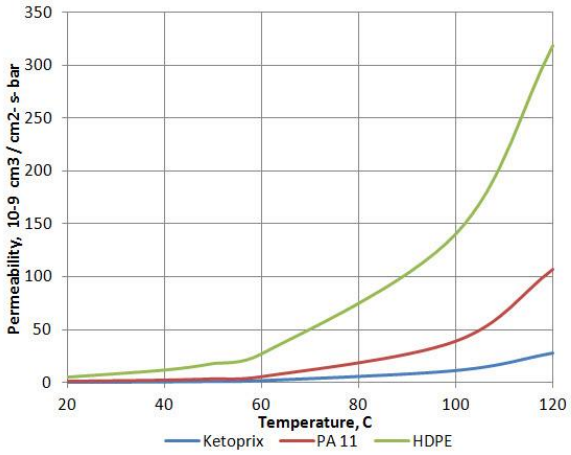
Graph 1. Hydrogen Permeability



Graph 2. Carbon Dioxide Permeability



Graph 3. Methane Permeability



Water vapor transport is another material characteristic important to the flexible packaging market where Ketoprix™ resins offer excellent performance. As can be seen from the data in Table 2 below, the water vapor transmission rate of Ketoprix™ polyketone resins are similar to that of EVOH and superior to that of films produced from oriented type 6 polyamide resins.

Table 2. Moisture Vapor Transmission Rates

Material	Relative Humidity	MVTR g-mil/100 in^2-day-atm
$EVOH_{32}$	90	3.4
$EVOH_{48}$	90	1.8
PA6 (oriented)	90	9
PK	90	3.7

One of the basic tenets of physical properties in polymers is that as strength increases, ductility (practical toughness or impact resistance) decreases. Ketoprix™ resins are an exception to this rule of

thumb in that they exhibit *both* high strength and high ductility, or toughness.

Two of the best measures of a material's ductility are the elongation at yield and elongation at break values. On an intuitive level, these properties define how much deformation the material can sustain before there is permanent/unrecoverable damage (yield), and how much deformation is required to produce complete failure (break). For film applications, this translates into excellent puncture and flex/crack performance. Unreinforced aliphatic polyketone resins exhibit tensile elongation values of 25% (@yield) and ≥ 250% (@break). It is worth noting that orientation during the film production process will produce much higher elongation values than those exhibited by injection molded test specimens, such as those that were used to generate these values.

That said, as can be seen from the data below when compared on an "apples to apples" basis with typical EVOH and Polyamide film resins, Ketoprix™ resins exhibit significantly greater ductility, as measured by tensile elongation, than do these other resins.

While the high tensile elongation at yield and break values exhibited by aliphatic polyketone resins are important performance advantages, what makes these characteristics truly unique is that, as shown in Table 3 Ketoprix™ resins *also* exhibit high strength values. It is this combination of strength and ductility/toughness which translates to a resin that offers a truly unique mechanical performance in flexible packaging applications.

Table 3. Strength & Ductility Comparison

Property		Units	PK	EVOH 32% PE	EVOH 48% PE	PA6
Tensile Strength	DAM Conditioned	MPa	60 60	34	27	80 35
Elongation @ yield	DAM Conditioned	%	25 25	- -	- -	
Elongation @ break	DAM Conditioned	%	250 270	15	20	4 >50

Conditioned: 23C @ 50% RH, 24 hours

In field use, virtually every film will come into contact with one or more reagents that may have a deleterious effect on the properties of the film. Logically enough then, one of the most important considerations when choosing a material for any given application is a material's resistance to attack by the chemicals with which it may come into contact during use. This is another area where the inherent properties of Ketoprix™ resin offer a significant advantage in film applications as polyketone exhibits resistance to attack by a broad range of reagents in a wide range of conditions.

There are two mechanisms by which a chemical attack occurs in polymers: solvation and chemical reaction. Due in large part to their dipolar (electrochemically neutral) semi-crystalline morphology, Ketoprix™ polyketone resins are resistant to

attack by both of these mechanisms in a wide range of chemical environments. Among the common classes of chemicals to which Ketoprix™ polyketone resins are resistant to attack by include:

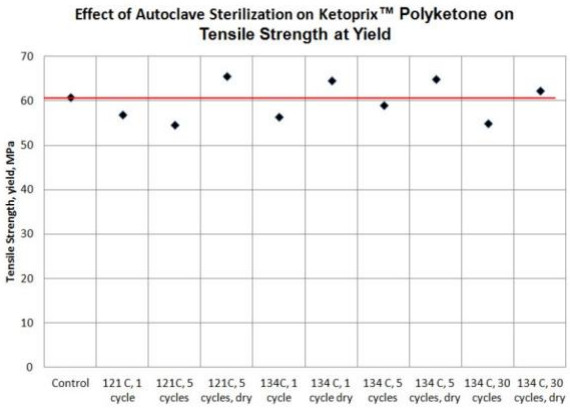
- Aliphatic & Aromatic Hydrocarbons
- Ketones, Esters & Ethers
- Inorganic Salt Solutions
- Weak Acids & Bases

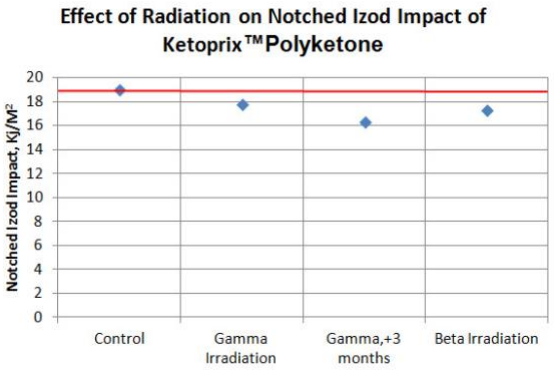
When a polymer experiences chemical attack this is typically first manifested in surface crazing, embrittlement or plasticization. While crazing is difficult to quantify in a meaningful way, embrittlement and plasticization (solvation) are manifested in the tensile elongation at break value. Accordingly then, retained tensile elongation values following immersion in reagents of interest for an extended period of time provides insight into the effects these chemicals have on any particular resin. In Table 4 below, retained tensile elongation values are provided for Ketoprix™ polyketone, and EVOH and Barex™ resins after 60 day immersions in various chemicals at 23 C. As this data clearly illustrates none of these chemicals had any significant effect on the tensile elongation of Ketoprix™ polyketone resin while both the EVOH and Barex™ resins showed significant effects from some of these exposures.

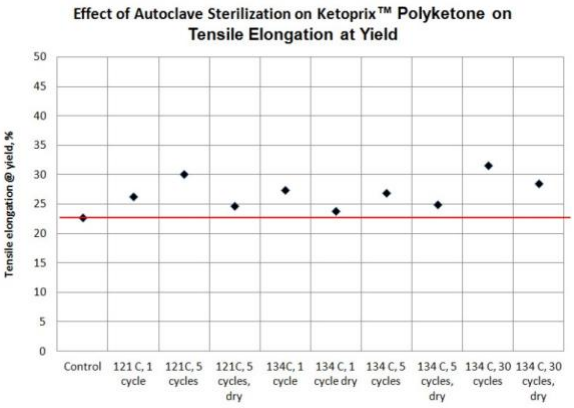
Table 4. Retained Tensile Strength Data After 60 days Immersion @ 23 C for Ketoprix™, EVOH and Barex™ resins

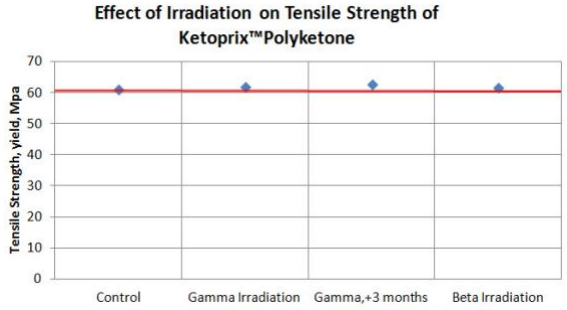
Solvent	Ketoprix ™	EVOH	Barex™
Ethyl Alcohol	112%	767%	60%
Ethylene Glycol	114%	676%	118%
Isopropyl Alcohol	112%	35%	180%
Benzene	108%	94%	108%
Toluene	97%	24%	108%
Xylene	110%	74%	123%
D-Limonene	101%	85%	188%
Acetone	105%	41%	370%
Methyl Ethyl Ketone	108%	35%	375%
Methyl Isobutyl Ketone	101%	35%	245%

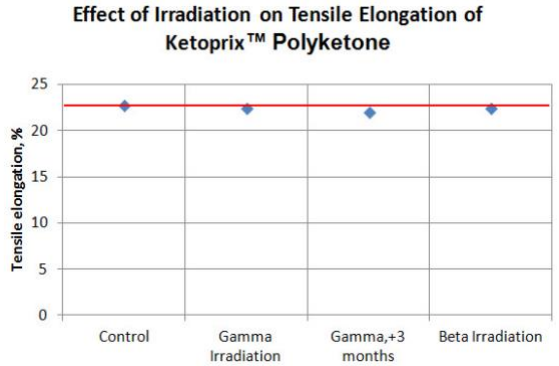
Any film which will be used to produce either a medical fluids bag or to seal a medical device package will necessarily be exposed to some form of sterilization or disinfection. Just as the molecular structure of Ketoprix™ conveys excellent chemical resistance to the resin, it also results in a material that is virtually impervious to all common forms of sterilization and disinfection including quarternary ammonium disinfectants. This is reflected in the graphs below which provide retained tensile strength and elongation values for Ketoprix™ polyketone resin after exposure to multiple cycles of autoclave, irradiation and steam sterilization.











As noted above, disinfection typically utilizes a quarternary ammonium compound that will attack many thermoplastic resins. However, as is shown in Table 5 below there was no loss of tensile strength with Ketoprix resin exposed to a 10% aqueous solution of ammonium hydroxide for 100 days at room temperature. It should be noted that 10% is a much higher concentration than is typically recommended or used with disinfectants and the exposure is much more severe than what would be experienced during cleaning. For example, one particular such disinfectant often used in medical facilities recommends a dilution rate of 1:256.

Table 5. Resistance to disinfection with ammonium hydroxide

Sample	Tensile Strength, psi	Tensile Elongation @ yield, %
Control	8,294	25
Exposed	8,294	23

Most films used in flexible packaging applications are multi-layer structures utilizing a combination of barrier and tie layer resins to achieve a particular combination of barrier properties. Polyethylene is one of the resins most commonly used in these films. Up until now, there have been no tie layer polymers effective in bonding aliphatic polyketone and polyolefins (PE,PP). However, this is no longer true as Esprix Technologies has developed a proprietary tie layer resin that can achieve inter-ply adhesion as high as 20 pli when used to adhere a Ketoprix™ polyketone film to a polyethylene film! As a result of this breakthrough development, it is now feasible to produce a wide range of multi-layer structures utilizing Ketoprix™ resins. This development now allows designers to tailor the barrier and mechanical properties of their packaging designs in ways that were previously not possible. This new tie layer resin is available for evaluations and is only available from Esprix Technologies.

To summarize, Ketoprix™ polyketone resins from Esprix Technologies provide the film producer and packaging design community a unique combination of barrier and mechanical properties along with excellent chemical and sterilization resistance. Furthermore, there now exists a new proprietary tie layer resin developed by Esprix Technologies, that enables flexible packaging applications to achieve previously unattainable mechanical and economic performance!

Want to know more about Ketoprix™ polyketone resins? Have an application with which you need some assistance? Please visit our website at www.esprixtech.com for product information or contact Mr. Dang Le at dle@esprixtech.com or 281-969-8763.