Utility & Advantages of Electron Beam Curing in Flexible Packaging

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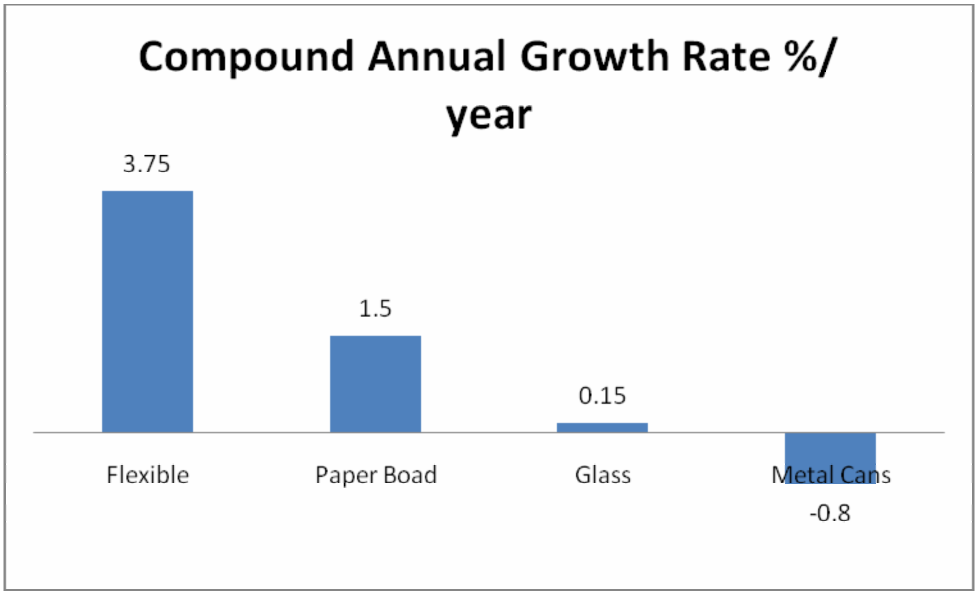
Introduction

Packaging is one of the largest areas of influence for consumers making purchase decisions. The global packaging market keeps growing, and it is now estimated to be around $450 billion. North American and European markets account for 29% and 27% of the $450 billion, respectively[1]. Consumers expect that the package has not only the protection of product and its visual impact as key functions but also functionality and consumer usefulness. Lightweight, functional, and inexpensive materials are preferable to the consumers. These properties are all achieved by flexible packaging; one of the biggest trends in recent packaging market. In fact, flexible packaging has been shown to experience a rapid growth in the last decade due to progress in polymer technology (Figure 1).

Trends in packaging technology[6]

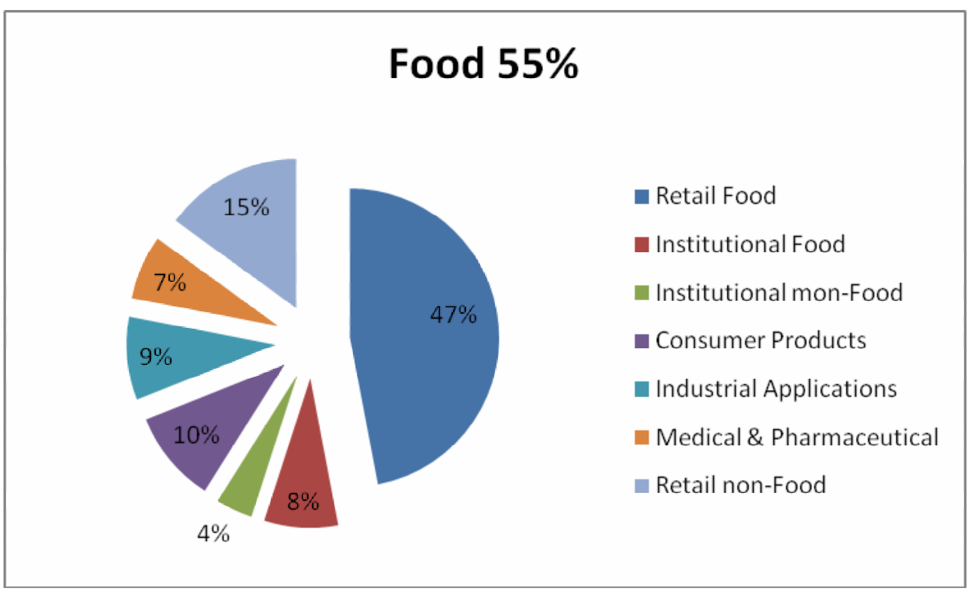
- Lighter packaging materials
- Simplification of converting process
- Shorter runs
- Emphasis on reducing/ eliminating migration risk

FIGURE 1: Packaging segments growth comparison 1996-2003[7]



The benefits of flexible packaging include reduction of utilized material, energy efficiency, and cost effectiveness. In the U.S., about 55% of flexible packaging is used in food packaging. Additionally, 7% is used in medical and pharmaceutical industries (Figure 2).

FIGURE 2: U.S. packaging sales breakdown by end-use segment, totaling $21.3 billion[7]



Flexible packaging satisfies customer's preferences, but it cannot be a substitute for other packaging materials if there is degredation in the quality of its barrier property. Conventional packages made from glass or metals have absolute barriers for moisture, gas and aromas and they keep the food products inside in desirable condition by not allowing the ingress of reactive compounds. Unlike these conventional materials flexible packages generally are permeable. This permeation of water vapor, gas, and aromas create a comprimised package. Creating a better barrier property with flexible materials is the key development goal in flexible packaging.

Electron Beam (E-Beam)Technology

The increased use of flexible packaging has driven a need for technologies to enhance flexible material's properties. The use of electron beam curing is becoming noticeable as a method to improve barrier properties in flexible packaging. Electron beam (E-beam) is an energy which is composed of a narrow stream of electrons in wave form. This energy is created from the acceleration and conversion of electricity. When a material is irradiated with E-beam, the material absorbs the energy and alters chemical bonds, which leads to modification of the material or could cause the death of living organisms when used as a sterilization process. This property of E-beam is noted and is used for a curing process (hardening a polymer material) in printing on package. This E-beam is also reported to be very effective in enhancing flexible package's barrier property.

Generally the lamination or combination of several polymers and their properties are used to create adequate barriers in flexible packaging and extend a product's shelf life. Examples of common available barrier materials are below (Table 1).

TABLE 1: Commonly available barrier materials used in flexible-packaging applications[7]

Material	Barrier Provided	Food Segment Commonly Used
BOPP, PE	Medium Moisture Barrier	Snacks, processed, meats/cheese
Metallized BOPP	High Moisture Barrier, Light barrier	Chips, Other Salty Snacks
Metallized PET	High Moisture, Oxygen and Aroma Barrier	Coffee, Tea, Ketchup, other Bag-in-Box, Wine
PVDC coated PET, & BOPP	High Oxygen Barrier, Medium Moisture Barrier	Processed Meats/Cheese
PET	Low Oxygen Barrier, Aroma Barrier	Low-Shelf Life Food Product, High Aroma Products like Wet Wipes
Nylon	Low Oxygen Barrier, Aroma Barrier	Some Meats, Non-Food
PVDC extruded	High Moisture, Oxygen and Aroma Barrier	Meats
EVOH Coex as a sealant Layer	High Oxygen Barrier, Aroma Barrier	Meats, Fruit Juices
Aluminum Foil, SiOx, AlOx	Absolute Oxygen, Aroma and Water barrier	Fruit Juices, Wines, Stand Up Pouches, Bag-in-Box

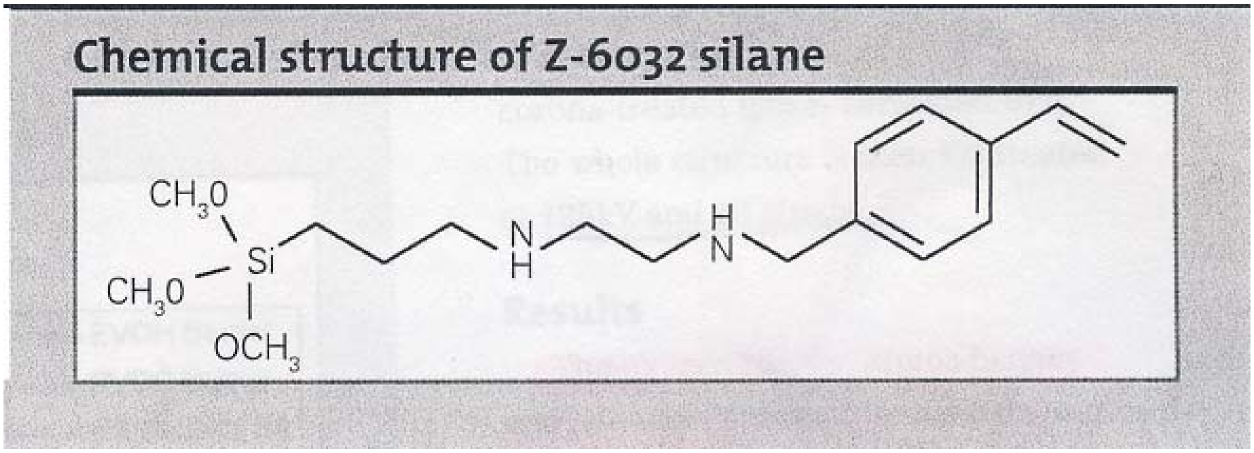
TABLE 2: Currently available meat and cheese pouch vs. proposed structure[7]

Current Structure	PET (12 micron) PVDC coating (3 micron) PU Adhesive (2 micron) PE Sealant (50 microns)	OR	PET (12 micron) PU Adhesive (2 micron) EVOH Sealant (50 micron)
Proposed Structure	PET (12 micron) EB Cured Barrier Adhesive (3 micron) PE Sealant (50 microns)		

Adhesive Enhancement (barrier)

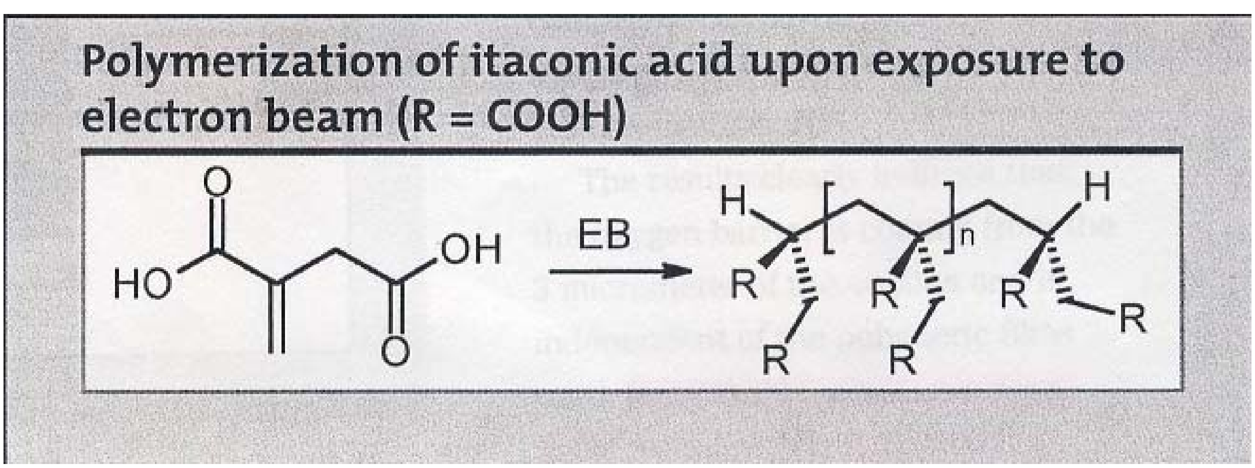
Instead of these common methods, an electron beam-cured laminating adhesive can create a great oxygen barrier innovatively. The barrier adhesives proposed are organo-functional silanes type Z-6032 (vinyl benzyl amine alkoxysilane) (Figure 3).

FIGURE 3: Chemical structure of Z-6032 silane[7]



Dow Corning and ESI established research to improve adhesion of metallized aluminum on BOPP and PET. Their hypothesis was that if the silanes are coated and metalized on polyolefin films with very low cost weight (<0.5gsm) and given E-beam curing, the vinyle group on this substance would attach to the polyolefin and make a SI-O-AL bonds, which would give requisite adhesion to the aluminum. The adhesion of the aluminum to the polyolefin was increased considerably. However, not only was the adhesion increased but also the gas barrier property of the metallized OPP structure improved. The unmetallized OPP also increased its barrier property.[2,3,4,5]

FIGURE 4: Polymerization of itaconic acid upon exposure to electron beam (R=COOH)[7]



The gas barrier property is related to the high polarity of the salt, which is created from the unsaturated carboxylic acid and the amino organofunctional silane. Electron beam curing of unsaturated carboxylic acid and cross linkage (Si-O-Si) provide the oxygen barrier in humid conditions with addition of desirable adhesion (Figure 5). The formulation of barrier adhesives and coatings are prepared as 60% solids in an isopropylalcohol (IPA) water mixture (50:50). Distribution of substances are 19% of Dow Corning 6601 (Silane grafted PEI), 71% of itaconic acid, and 10% of bis-gamma-triethoxysilyl propylamine. In the formulation it is possible to avoid using methanol, ethoxy silanes can be used as substitution. As solvents are carried in this formulation, E-beam-thermal hybrid curing is required. The application technique is to reverse roll a film which is treated with corona. The film is unwound from large roll and goes through a coating station. The adhesive is then dried to evaporate the solvent and water and the second corona-treated film is laminated onto it (Figure 8). In this process energies of 125kV and 10 Mrads are used for E-beam treatments.

Compared to the commonly used barrier materials, which are typically PVDC coating and EVOH for PET/LDPE laminations, E-beam cured barrier adhesive is competitive in oxygen transmission rate (OTR) at up to 80% relative humidity (Figure 6). E-beam energy has also shown to increase barrier properties at extremenly high humidities as demonstrated in Figure 7, where higher doses create better gas barrier properties at relative humidities of 90%. The result of the investigation demonstrated the oxygen and aroma barriers and adequate adhesion were obtained in various polymeric films by using process with E-beam curing (Table 3). Additionally, the silane-crosslinked adhesive enhances tear resistance, elongation at break, abrasion resistance, thermal stability and moisture resistance. Electron beam creates a highly linked structure in the packaging material allowing very low migration of compounds.

FIGURE 5: Silane condensation upon exposure to moisture[7]

$RSi(OMe)_3 + HOH \rightarrow\rightarrow\rightarrow RSi(OMe)_2OH + MeOH$

$RSi(OMe)_2OH + HOH \rightarrow\rightarrow\rightarrow RSi(OMe)(OH)_2 + MeOH$

$RSi(OMe)(OH)_2 + HOH \rightarrow\rightarrow\rightarrow RSi(OH)_3 + MeOH$

$RSi(OMe)_3 \rightarrow\rightarrow\rightarrow RSiO_{1.5} + 1.5HOH$

TABLE 3: Oxygen barrier, aroma barrier and adhesion of various polymeric materials prepared by the EB-cured barrier adhesive[7]

Material	O_2 Barrier at RH 50% and T = 23 °C cc/m^2/24hrs	O_2 Barrier at RH 80% and T = 23 °C cc/m^2/24hrs	Aroma Barrier	Adhesion
Pet12M/BA3M/LLDPE50M	1.0	9.6	Excellent	Substrate Tear
OPP18M/BA3M/OPP18M	1.0	7.8	Excellent	Substrate Tear
OPPmet18M/BA3M/OPP18M	0.8	0.8	Excellent	Substrate Tear
LDPE50M/BA3M/LDPE50M	1.5	9.0	Excellent	600gms/inch
OPP30M/BC3M	2.0	10.0	Excellent	NA

*Oxygen barrier measured by Mocon Oxtran 2/20 series. Aroma barrier measured by in-house developed testing method for both polar and non-polar constituents.

FIGURE 6: OTR of different barrier materials for PET/LDPE laminate T=23°C[7]

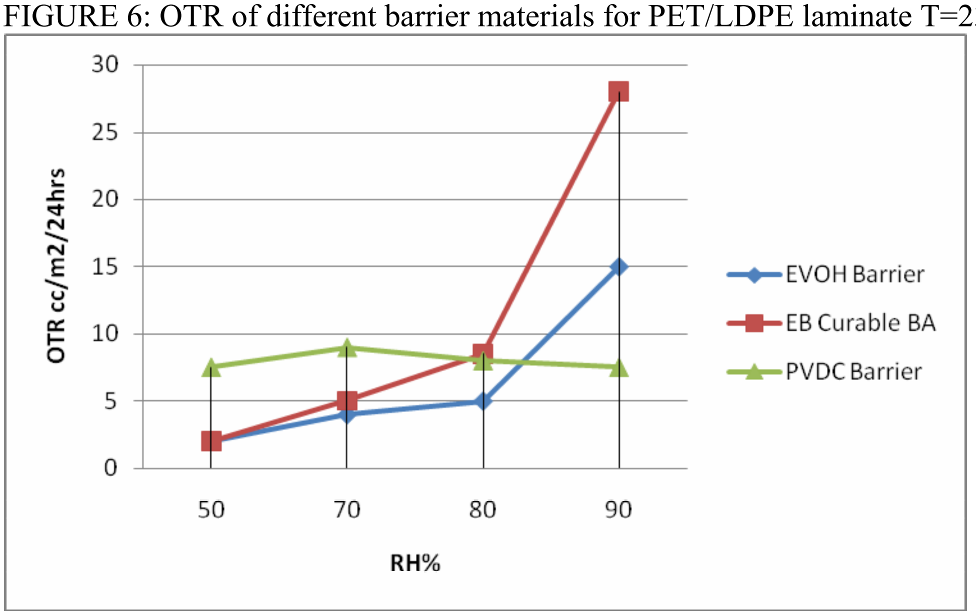


FIGURE 7: OTR of PET/BA/LDPE BA thickness as a function of RHT = 23°C[7]

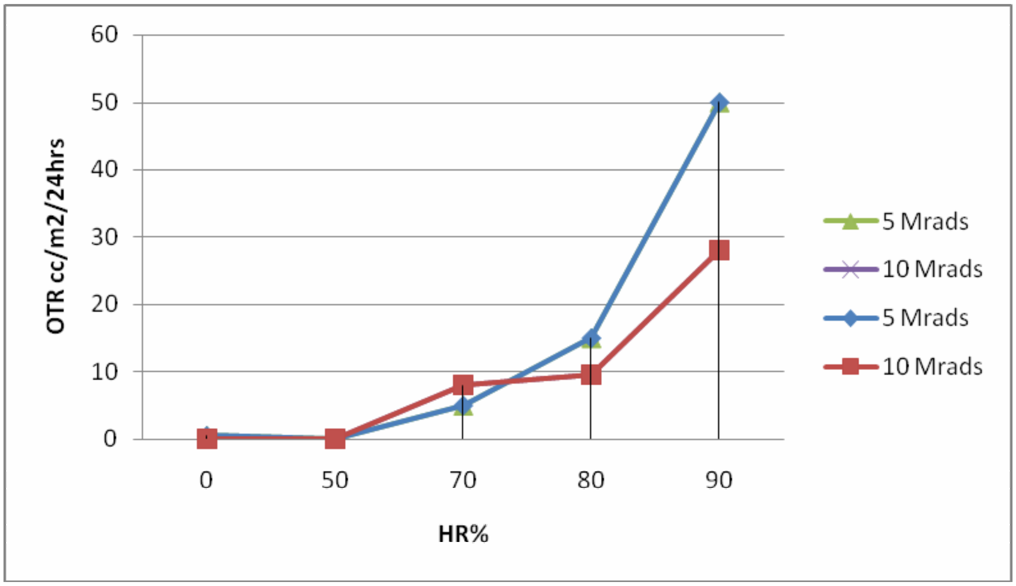
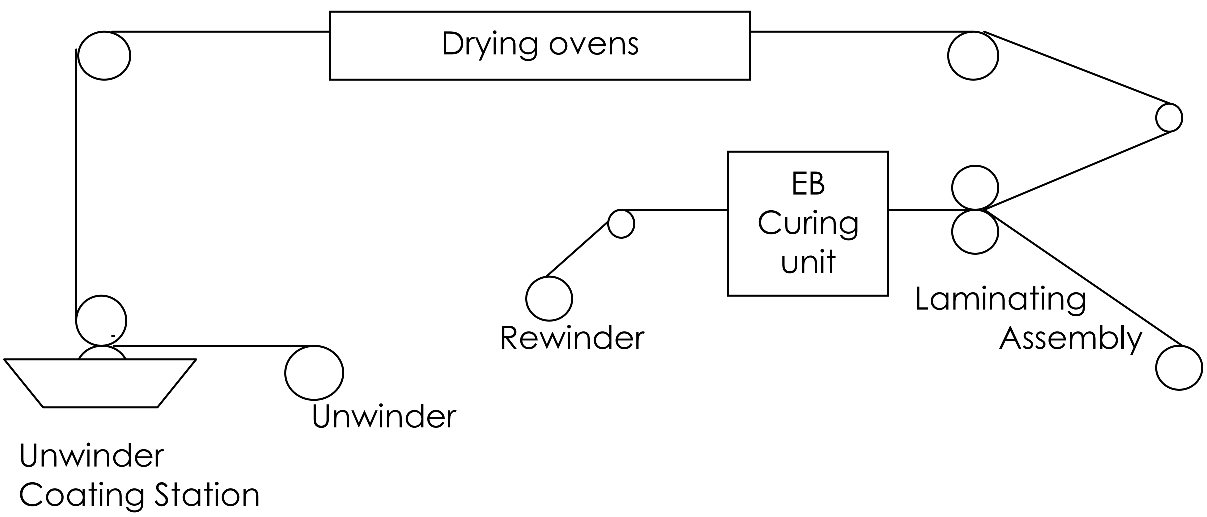


FIGURE 8: EB-cured barrier adhesive process[7]



E-Beam In-Process Systems

E-beam curing is useful not only in improving adhesion and the gas barrier property, but also in improving the printing process as a cure agent while being economical. Printing images and text is an important process in packaging because decoration of packages is essential in attracting consumers to the product. E-beam curing enhances print quality by increasing the color and image fidelity. Early E-beam curing methods were known for their high cost attributable to plant and equipment capital investment. Manufacturing goals attempt to reduce operation costs; therefore, converting conventional methods to an expensive E-beam curing method was a difficult decision to make at that time. The progress in the technology has driven the costs down so today it is a viable option.

Advantages of EB curing

- No VOCs
- Energy efficient
- High consistency
- High resistance
- Ability to penetrate
- Low extractables

Simplification of the processing line is key in cost reduction. Having a single E-beam curing station on the end of the print line differs from the standard UV curing processes with multiple lamps which require maintenance and calibration. A single E-beam station makes the process simpler. In traditional printing lines (Flexo and gravure), a chill drum is used to cool the substrate and set the printing and adhesive, conversely, the application of a low heat of E-beam curing process requires no cooling station and simplifies the line. The elimination of a few stations or steps in printing line reduces energy cost in production. Less machinery means less production space. The shorter line provides higher production efficiency and lower operation costs.

The recent limitation of volatile organic compounds (VOC) by the EPA is one of the reasons for switching to E-beam curing system which does not use VOC's. In a conventional system, the top layer (outer layer) of a film is solvent borne and this allows VOC gas to be emitted. On the contrary, in an E-beam cure system, reactive diluents are the components of top layer which do not emit VOCs. As emissions regulations of VOC's continue to get tighter and tighter, especially in food industries, manufactures are apprehensive about potential food safety issues.

Summary

E-beam curing works well with heat sensitive film materials because it is a very low heat application. This fact allows manufactures to have more choices in materials. The advantages of improved adhesive application, barrier enhancement, and process cost reduction have made this advanced technology very attractive to its users. These facts are driving the increased utilization of E-beam curing. The future of E-beam curing seems bright due to several advantages gained by using the technology. Certainly this innovative and economical packaging process will be widely used in flexible packaging.

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