INSTANT INNOVATION: PRODUCT DEVELOPMENT USING E-BEAM IRRADIATION

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ABSTRACT

Billions of dollars worth of formed plastic parts, such as heat-shrinkables, plumbing pipe, wire and gaskets, are created each year through the use of e-beam irradiation. E-beam processing is a powerful tool – used behind the scenes – to produce new products or to improve existing ones. This efficient, cost-effective processing step modifies the molecular structure of plastics to create significant property improvements in finished parts. This paper describes an easy experimental approach that will quickly reveal the enhancements to be gained for existing and developmental products through e-beam processing. 'Instant innovation' can be achieved with a few simple steps within a few weeks. Two product development project examples are discussed along with examples of successful commercial applications. Various production methods, material property improvements, and key benefits of the technology are also illustrated.

INTRODUCTION

Product development specialists have all been there: continuous improvement is expected, but there are no immediate solutions to the issues of material performance; and the creative juices are just not flowing. Redesign of the part or the use of an expensive engineering plastic are possible alternatives – but what are the costs and what about project timing? E-beam irradiation can be the technological tool to address the improvement imperative. This paper describes a workable approach for using a *proven* tool that is nevertheless *unfamiliar* to most material scientists. High material performance can be obtained with commodity resins, and results can be demonstrated in a short timeframe. Instant innovation is only three steps away.

E-BEAM PRODUCT DEVELOPMENT GUIDE

The first step of the e-beam product development process is to identify a potential product improvement or a cost-reduction opportunity and then contact a "contract" e-beam irradiation service provider to discuss the application. With identification of the material and application, an initial screening experiment can be designed with the no-charge assistance of the e-beam specialist. The overnight delivery and actual dosing of the product samples can be achieved in only a few days.

Once the samples have been processed via e-beam, the second step is to test the samples to determine the property improvements of the material. These first two steps may be an iterative process as it may be necessary to fine tune the dose or the product formulation.

The third step in developing a new product is to validate the process using the intended packaging and to qualify the process in a production environment. Again, with the help of an e-beam specialist, the most efficient and cost-effective methods available can be determined.

Thus, in three steps, a new product is created. The entire process can take less than a month, with the testing of the parts often being the longest step.

MATERIALS AND PROPERTIES

Property improvements in many polymers can be attained through e-beam processing. Commodity resins including polyethylene (PE) and polyvinyl chloride (PVC) as well as other common polymers such as polyamides (PA), polyethylene copolymers (e.g. ethylene vinyl acetate (EVA) and polyimides),

Table 1: Commercial Examples

Example	Typical Polymer(s)	Property Improved Due to E-Beam Processing
Angioplasty balloon	PE	Tensile strength; controlled balloon size[6,7,8]
Artificial hip joints	Ultrahigh molecular weight polyethylene (UHMWPE)	Increased wear resistance[9,10,11]
Corrugated piping	EVA	Significantly increased alternate bending fatigue[12]
Foam	PE	Improved cell structure, mechanical properties and appearance[13.14,15]
Gaskets, seals	PE, EVA, thermoplastic elastomers (TPE)	Improved heat properties, chemical resistance and resistance to compression set[16,17]
Heat shrinkables	PVC, PE, PVDF	"Memory" imparted, chemical resistance[18,19]
Medical devices	Most all including polypropylene	Sterilization[1]
Molded parts (electronic components)	PA	Solder iron resistance[12]
Molded parts (automotive)	PA	Improved heat deflection and operating temperature[12]
PEX – crosslinked flexible pipe	PE	Increased heat distortion temperature, operating temperature and dimensional stability[20]
Recycling of raw materials	PTFE	Micronized powders used in inks, lubricants and coatings[1,5]
Resin pellets	Various	Rheology modification; unique visual effects in finished parts[1,2]
Rubber	Various	Cold vulcanization[21,22,23]
Self-regulating heat cable	PE	Temperature control (e.g. electric blankets)[24,25]
Solvent-free coatings	Monomer/oligimer	Curing creating improved mechanical properties and functionalization[26,27,28]
Wire and cable insulation	PVC, PE	High temperature properties, chemical resistance, tensile strength; "low smoke/zero halogen" (PE)[29,30,31]

neoprene, silicone and ethylene-propylene rubbers (EPR) can all realize substantial property enhancement. Property improvements for these materials may include an increase in tensile strength, impact strength, abrasion resistance, chemical resistance, heat deflection, modulus, hardness, service temperature, barrier properties, stress-crack resistance, creep resistance and fatigue resistance. Other special attributes can be imparted such as heat shrink properties, positive temperature coefficient properties, or, in the case of polytetrafluoroethylene (PTFE), fractionation enabling the creation of micropowders. Electron beam processing is also used for crystal structure modification (gem stone coloration) and to increase silicon switching speed, further demonstrating the power and breadth of possibilities.[1,2,3,4,5]

The table above shows just a fraction of the many types of products that are created or improved via e-beam processing. Applications include appliance parts, gears, pump vanes, housings, manifolds, tubing, electrical connectors, sporting goods and bottles. The possibilities are endless. Often e-beam processing is the unacknowledged "secret" to making great products.

Product Development Examples

Two product development examples are described below, with differing application objectives and associated constraints.

Part #1: Fluoroelastomer Gaskets and O-Rings
Objective: Improve strength properties while maintaining ultra-pure material characteristics.

Process:
Step 1: The application was discussed and an experiment was conducted at a contract e-beam service provider. A number of o-ring samples were fabricated and irradiated to various dose levels.
Step 2: The samples were subsequently tested and it was determined that improvements to the targeted properties were in fact achieved.
Step 3: The next phase of product design was started to achieve a new product that fills a void in the market where more robust properties are required.
Result: Potential applications for these materials are seals and gaskets used in FDA-regulated food contact process equipment and ultra pure processing environments in the semi-conductor industry. The use of these materials for these demanding applications is possible because there are no residuals typically associated with the use of thermo-chemical crosslink agents. The development process proved that e-beam technology can quickly create innovative products.

While some products can be developed without a project deadline, there are many cases where the timeline is a crucial factor, such as in the need to meet a changing quality standard. This second case involved the development of a product to meet a new quality test and was an urgent matter where an immediate solution was needed.

Part #2: Polyethylene Gasoline Tanks
Objective: Pass a newly-passed flame resistance test requirement
Process:
Step 1: The customer took the first step of contacting a contract e-beam service provider and discussing the need to meet the new standard in one of their markets. An initial experiment was performed at different dose levels. Total time to completion was one week from the initial contact to the return of the samples.
Step 2: The product testing revealed the lowest dose was all that was needed to pass the test.
Step 3: Since the product had not changed, other than being crosslinked, the qualification process for the third step was brief.
Result: The 'instant innovation' took about a month for the product to pass the flame resistance testing and go on-line. With the timeliness and efficiency of e-beam processing, the customer was able to supply a new, enhanced product which meets the higher standards.

ENGINEERING ADVANTAGE

Using e-beam technology to modify materials for specific applications can reduce costs and time in the initial development of a product.

A snowmobile provides an example of the engineering advantage offered by e-beam processing. Snowmobiles have many parts made from polyethylene due to its good low temperature properties. With the advantage of e-beam processing, numerous parts can be further improved to provide a superior vehicle – without the addition of engineered polymers. E-beam processing increases the impact strength, especially at low temperatures, of body parts which take a beating. It provides greater heat resistance and less distortion of the parts around the engine and exhaust. It also provides greater wear resistance for those parts in constant contact with the snow such as the runners. It can even decrease the permeation rate of the fuel tank and increase the flame retardant properties. The tensile strength of key parts can also be improved due to e-beam processing. Rather than using different materials for each component, one irradiated material for each part leads to simpler engineering, lower raw material costs, and subsequently a more rapid development process – not to mention more cost effective manufacturing.

SPECIFICS

Technology
The remarkable effectiveness of e-beam processing occurs at the molecular level. The

process utilizes ionizing radiation in the form of accelerated electrons which interact with matter by transferring energy to the electrons orbiting the atomic nuclei of target materials. These electrons may then be either released from atoms, yielding positively charged ions and free electrons, or moved to a higher-energy atomic orbital, yielding an excited atom or molecule (free radical). These ions, electrons and excited species are the precursors of any chemical changes observed in irradiated material. At this point, crosslinking occurs in many materials. The amount of energy absorbed, also known as dose, is measured in units of kilogray (kGy), or megarad (MR or Mrad). One Mrad (10 kGy) is equal to 1,000,000 ergs per gram.[1]

Polymer Response to Irradiation
Polymers generally respond to e-beam processing in one of three ways. The polymer may crosslink in which the molecular weight increases and the properties improve accordingly. The polymer may degrade due to chain scissioning, which in certain industries is an effective means of producing materials that could not otherwise be cost-effectively manufactured, for example PTFE micropowders. Finally, the polymer may be radiation resistant where no significant degree of either crosslinking or chain scission occurs. This resistance is attributable to molecular protection typically afforded by means of an aromatic ring. This property is important to the medical device industry, which uses electron beams for medical device sterilization. Crosslinking is the polymer response most often desired, and it can be more efficient with the use of additives such as multifunctional monomers.[32]

Processing Methods
Finding the most cost-effective way to process materials is of interest to both the customer and the e-beam service provider as process efficiencies play a large role in total economics. Many processing methods have been developed which can handle a wide variety of product types.

The use of a horizontal cart conveyor system is preferable when processing individual items or a quantity of product where the loading has been established based on bulk density or based on well-organized and validated boxed configurations. The conveyor system affords efficient processing of these materials. A wide variety of products, ranging from bulk resins and powders, to small plastic parts, to tubing coils packaged in cases, are all processed using a conveyor system. Other examples include products irradiated for sterilization purposes such as medical devices and pharmaceutical products.

To process wire, cable, tubing and other reel-to-reel product, festooning fixtures are available in which the product passes many times under the beam. Processing speeds can reach up to 1000 feet per minute (and much higher in some applications). Products as delicate as catheter tubing and as heavy as three inch diameter electrical cables are e-beam processed.

Rolls of sheet materials can also be processed continuously via e-beam processing. The use of e-beam technology results in consistent crosslinking throughout the product and across the web. This is difficult, if not impossible, to achieve with chemical methods.

Contract E-Beam Processing vs. Owning a Beam
The use of an e-beam contract service provider is usually the most cost-effective way to manufacture innovative products via irradiation. The purchase and installation of all the components of an e-beam system is complex and capital intensive, and the time needed for a new facility to be designed, built and qualified can be two years or more. In addition, the inherent capacity of an e-beam is unlikely to be filled with an individual product line, making it difficult to recover the initial capital expense in a timely manner. The operation of an e-beam also requires specialized maintenance and oversight due to regulatory constraints.

A contract provider, or “toll processor,” specializes in e-beam processing and has the knowledge, capacity and flexibility to serve many customers, whether small or large. If a product line grows large enough to justify the cost of an e-beam, a contract provider can provide the ramp-up capacity until the beam is on-line, at which point it can serve as back-up capacity. Contract e-beam services providers are strategically located across the United States.

Benefits of E-Beam Processing

Most manufacturing companies exist in a competitive environment in which *innovation* and *cost reduction* are rewarded and “business-as-usual” is punished. E-beam processing adds value to an extraordinarily wide range of *innovative* products. *Cost-reduction* is achieved when commodity resins are used in conjunction with e-beam processing instead of high cost engineered materials.

Additional benefits include environmental friendliness due to the absence of chemical additives typically used in alternative material modification processes. The reproducible process control of e-beam does not rely on a radioactive material for its energy source but is rather a simple, clean “on-off” technology that uses electricity. Any scrap is typically recyclable because only properly-formed parts are crosslinked. The process can be outsourced to reduce operating expense and minimize capital investment. Logistics can be favorable because of the many e-beam sites nationwide.[1,33]

Should a company evaluate (or at least consider) e-beam processing? The benefits and costs say *yes*. The next question is: *Can* a company evaluate e-beam processing enhancement – quickly? efficiently? effectively? This paper attempts to demonstrate that the answer to all three is yes. Because e-beam processing has been used for decades in the creation of innovative products, extensive technical literature and explanatory patents are readily available covering a wide variety of materials and a wide variety of applications. These resources can be used to trigger idea generation and then to support the development of successful new products.

CONCLUSION

New products and improved materials can be created through a simple development process using e-beam. The rapid completion of feasibility studies means your products get to market quicker. The use of the “not so secret” e-beam process has and will continue to produce novel products through ‘instant innovation.’

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