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2006-11

Suitability of typical electrical insulating material (EIM) for polymer recycling

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International Electrotechnical Commission, 3, rue de Varembé, PO Box 131, CH-1211 Geneva 20, Switzerland
Telephone: +41 22 919 02 11 Telefax: +41 22 919 03 00 E-mail: inmail@iec.ch Web: www.iec.ch

Commission Electrotechnique Internationale
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SUITABILITY OF TYPICAL ELECTRICAL INSULATING MATERIAL (EIM) FOR POLYMER RECYCLING

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IEC 62392, which is a technical report, has been prepared by IEC technical committee 112: Evaluation and qualification of electrical insulating materials and systems.[1]

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
15/235/DTR	15/263/RVC

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1 Technical committee 112 was created by combining the activities of sub-committee 15E and techical committee 98. This project was initially developed in technical committee 15 and then transferred to technical committee 112.

Full information on the voting for the approval of this technical report can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the maintenance result date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

SUITABILITY OF TYPICAL ELECTRICAL INSULATING MATERIAL (EIM) FOR POLYMER RECYCLING

1 Scope

This Technical Report gives information for the assessment of factors associated with the polymer recycling and/or reuse of typical insulating materials in electrotechnical equipment. It gives information and assistance to developers and design engineers for assessment in selecting polymers and polymer combinations, and is a contribution to the preservation of resources and the minimization of disposal costs at the end of a product life. The environmental compatibility of polymers must be assessed in the light of the function of the materials in the product and the total service life. An important aspect is the recovery of the material at the end of the product life. The value level of material recycling as recovery option can be improved by incorporation of suitability for dismantling into the design of the article and the choice of insulating materials which are generally used. This document will cover material recycling only as part of recovery.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60093, *Methods of test for volume resistivity and surface resistivity of solid electrical insulating materials*

IEC 60112, *Method for the determination of the proof and the comparative tracking indices of solid insulating materials*

IEC 60216-1, *Electrical insulating materials – Properties of thermal endurance – Part 1: Ageing procedures and evaluation of test results*

IEC 60216-2, *Electrical insulating materials – Thermal endurance properties – Part 2: Determination of thermal endurance properties of electrical insulating materials – Choice of test criteria*

IEC 60216-3, *Electrical insulating materials – Thermal endurance properties – Part 3: Instructions for calculating thermal endurance characteristics*

IEC 60216-4-1, *Electrical insulating materials – Thermal endurance properties – Part 4-1: Ageing ovens – Single-chamber ovens*

IEC 60216-4-2, *Electrical insulating materials – Thermal endurance properties – Part 4-2: Ageing ovens – Precision ovens for use up to 300 °C*

IEC 60216-4-3, *Electrical insulating materials – Thermal endurance properties – Part 4-3: Ageing ovens – Multi-chamber ovens*

IEC 60216-5, *Electrical insulating materials – Thermal endurance properties – Part 5: Determination of relative thermal endurance index (RTE) of an insulating material*

IEC 60216-6, *Electrical insulating materials – Thermal endurance properties – Part 6: Determination of thermal endurance indices (TI and RTE) of an insulating material using the fixed time frame method*

IEC 60505, *Evaluation and qualification of electrical insulation systems*

IEC 61244-3, *Long-term radiation ageing in polymers – Part 3: Procedures for in-service monitoring of low-voltage cable materials*

ISO 179 (all parts), *Plastics – Determination of Charpy impact properties*

ISO 527 (all parts), *Plastics – Determination of tensile properties*

ISO 11469, *Plastics – Generic identification and marking of plastics products*

ISO 1043-1, *Plastics – Symbols and abbreviated terms – Part 1: Basic polymers and their special characteristics*

ISO 1043-2, *Plastics – Symbols and abbreviated terms – Part 2: Fillers and reinforcing materials*

ISO 1043-3, *Plastics – Symbols and abbreviated terms – Part 3: Plasticizers*

ISO 1043-4, *Plastics – Symbols and abbreviated terms – Part 4: Flame retardants*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
electrical insulating material
EIM
material with negligibly low electric conductivity, used to separate conducting parts at different electrical potentials

[IEV 212-01-01:1990, MOD]

3.2
composite

1) solid product consisting of two or more distinct phases, including a binding material (matrix) and a particulate or fibrous material

   NOTE Example: Moulding material containing reinforcing fibres, particulate fillers or hollow spheres.

2) solid product consisting of two or more layers (often in a symmetrical assembly) of plastic film or sheet, normal or syntactic cellular plastic, metal, wood, composite according to definition 1), etc. with or without adhesive interlayers

   NOTE Examples: Film composites for packaging, sandwich cellular composite for structural applications, laminates made with paper, fabric, etc.

[ISO 472: 1999]

3.3
(mechanical) recycling
reprocessing in a production process of the waste materials for the original purpose or for other purposes but excluding energy recovery

[IEC Guide 109:2003]

NOTE This definition excludes the chemical recycling during which the molecular structure is broken down to produce monomers.

3.4
feedstock recycling
processing of plastic waste material, with significant change to the chemical structure of the material including cracking, gasification and de-polymerisation but excluding energy recovery or incineration

3.5
recyclability
property of a substance or a material and parts/products made thereof that makes it possible for them to be recycled

NOTE Recyclability of a product is not only determined by the recyclability of the materials it contains. Product structure and logistics are also very important factors.

[IEC Guide 109, 2003]

3.6
recycled polymer
materials resulting from recycling

3.7
commingled
A mixture of materials or products consisting of different types of plastics

3.8
contamination
unwanted substance in polymeric materials according to the intended use

3.9
halogen containing
material containing the elements F, Cl or Br either in the polymer (as in PVC, PTFE, …) or in the fire-retardant additive package

3.10
thermoplastic
plastic capable of being repeatedly softened by heating and hardened by cooling through a temperature range characteristic of the plastic and, in the softened state, capable of being repeatedly shaped by flow into articles by moulding, extrusion or forming

NOTE 1 Thermoplastics can be reprocessed and recycled by remelting.

NOTE 2 Examples are given below as abbreviations after ISO 1043-1: PE, PVC, PS, PC, PP, PA, POM, SAN, ABS, PBT, PET, PMMA, ASA, TPU, LCP, PEEK, PPS, PBT + PC, PC + ABS, PC + PBT, PPE, PPE + PS.

3.11
thermoplastic elastomer
TPE
general term for specific elastomers like thermoplastic polyurethane (TPU)

NOTE For further abbreviations see ISO 18064:2003.

3.12
elastomer and other crosslinked polymer
macromolecular material which returns rapidly to approximately its initial dimensions and shape after substantial deformation by a week stress and release of the stress

NOTE 1 The definition applies to room temperature test conditions.

NOTE 2 Examples are EPR, nitril rubber, cross-linked PE according to ISO 1629 and ISO 1382 and cross-linked PE (PE-X according to ISO 1043-1).

3.13
thermoset
plastic which, when cured by heat or other means, changes into a substantially infusible and insoluble product

NOTE 1 Thermosets are often called thermosetting before curing and thermosets after cure. Their polymeric structure is cross-linked by curing.

NOTE 2 Examples are EP, SI, UP, MF, PF, UF, MP, PUR (thermoset polyurethane, PIR (polyisocyanurate).

NOTE 3 For a more complete list of vocabulary see ISO 472.

4 Environmental aspects of polymeric materials at the End Of Life (EOL) stage

The choice of the polymeric material for electrical applications should be done incorporating environmental considerations from a life cycle perspective. Handling of polymer waste is an important issue in the life cycle of polymers. Polymer waste can be recycled, incinerated or landfilled. Landfill deposition should be avoided, as it implies no recovery of materials or energy and may cause uncontrolled release of harmful additives or degradation products. Thus, the options that should be considered are mechanical recycling, feedstock recycling which may be the choice in case the material is commingled, and incineration with energy recovery. Overview of possible ways to recover polymers is shown in Figure 1.

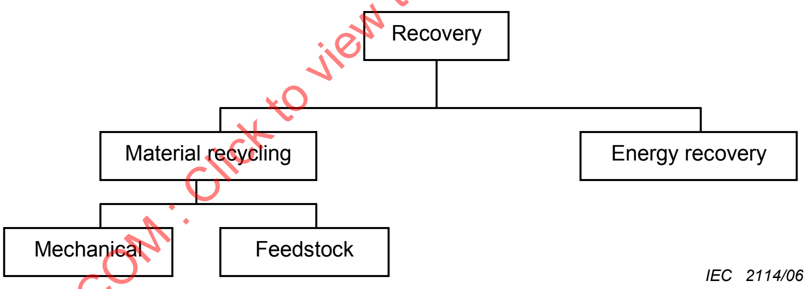


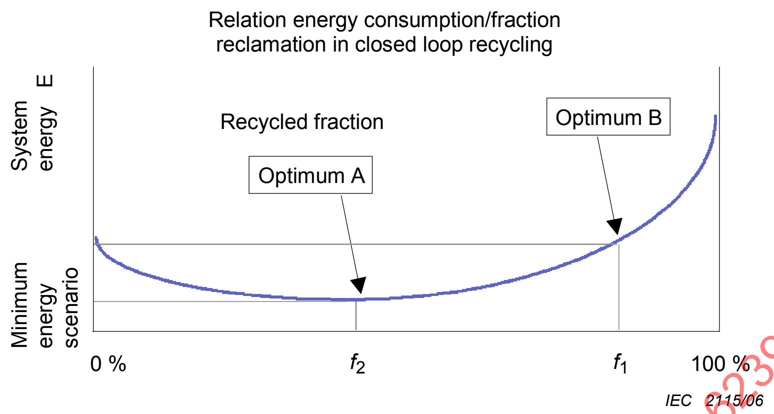
Figure 1 – Overview of possible ways to recover polymers

Mechanical recycling may be the choice if the waste material comply with the requirements of the recycling process intended to be used, and well-defined and there is an efficient infra-structure for collection, dismantling, and re-processing into new products.

However, if recycling conditions are not fulfilled, incineration with energy recovery is probably the most suitable treatment. Using polymer waste as fuel for power/heat generation is advantageous when the polymers have a high energy content. It is important, however, that incineration is carried out under controlled conditions in plants with efficient air pollution control. Polymers may for instance contain nitrogen, chlorine, fluorine, bromine and sulphur in their structure or in additives and combustion of such compounds may give rise to harmful substances. The preferred and most appropriate treatment of polymer waste containing undesired organic additives is incineration, enabling the destruction and removal of harmful compounds.

Whether or not a product or product part should be reused, recycled or incinerated is a complex issue which has to be considered from case to case.

Recycling of thermoplastic-based products is increasing. The recycling environmental benefits depend on the efficiency of the collecting mechanisms because the impacts arising from the collection could eliminate the environmental credits due to the recycled material availability. Energy consumption and recycled fraction are shown in Figure 2.



Environmental efficiency of a recovery program

optimum A = maximum energy recovery

optimum B = maximum material recovery in respect of energy balance

Figure 2 – Energy consumption and recycled fraction

If thermoplastics are incinerated under unregulated conditions with no air pollution control, harmful combustion products may be emitted into the air. This is particularly true if the polymer has other atoms than carbon, hydrogen and oxygen present in its structure (or in additives). Incineration of nitrogen-containing polymers induces the formation of cyanides/ cyanates and NO_x, whereas hazardous halogenated organic compounds (dioxins, furans, etc.) may be formed under inappropriate incineration of halogen-containing polymers. If the latter polymers are incinerated in a plant with tuned combustion conditions, the halogens will come out as acids (HCl, HF) in the combustion gases. These acids can be neutralised with common air pollution control equipment.

If thermoplastics are deposited at a landfill site, the complete degradation of the material may take more than a century, and during this time span harmful additives (e.g. lead-based stabilisers) may be leached from the landfill site. It is generally accepted that land filling is not preferred. Incineration should be done under state of the art conditions.

Thermosets are currently not recycled to a great extent. Recycling is restricted to milling and use of the resultant powder as a filler. Methods for chemical recycling of thermosets, i.e. controlled degradation and recovery of components, have been developed but are presently not used on a large scale. If a thermoset resin contains substances which are classified as environmentally hazardous, then the waste may also be environmentally hazardous depending on applicable legislation.

Recycling of rubber materials has so far been limited to grinding and use of the milled rubber as a filler in other materials such as asphalt and athletic field materials. Rubbers may contain metal compounds (additives) which are classified as environmentally hazardous, which means that the waste is classified as environmentally hazardous. Thermoplastic elastomers can be recycled as the thermoplastics.

At the same time that plastic parts have been substituted for metals in many applications, plastic recycling has become more difficult. Special plastic composites, such as those with glass additives, require special separation. The introduction of more powerful electronic products, more sensitive to electronic noise, has led to the use of plastic resins containing conductive stainless steel fibers, further complicating separation for recycling. Embedded metal fasteners in moulded plastics have long created recycling problems.

5 Processing and separation of recycled materials

5.1 General

Excluding land filling, there are three main options for the recovery of the polymeric electrical-insulating materials:

– material recycling;
– recovery of raw materials;
– energy recovery.

Thermosets, chemically crosslinked thermosets, elastomers – crosslinked PE and some not crosslinked but unmeltable polymers like PTFE – cannot be reprocessed as recovered materials. They can be grinded to powder or granules and incorporated as a filler or – alternatively – decomposed thermically, chemically or by irradiation.

The material recycling requires a level of separation to obtain the recyclate quality compatible with the intended recycling process. Alternatively, other options can perform better especially for complex mixed material fractions

5.2 Separation methods

The basic separation processes are as follows:

a) Separation based on polymer density

The separation in water of the materials below and above a relative density of 1,00 is the easiest to perform.

A heavy-media flotation where fine solids such as brine are added into water to increase its relative density is also possible.

By having several density baths in the processing line, several density cuts could be established, sorting out polymers and other materials by density.

b) Separation based on polymers surface properties

Froth flotation uses additives in water, such as pine oil, to modify the polymers surface properties. Gas bubbles that are injected in the flotation bath bottom attach to certain hydrophobic polymer(s). The gas bubble lifts the polymer grain up to the bath surface where it can be recovered.

c) Separation based on polymers softening temperatures (i.e. thermo-adhesion). By heating polymers, certain achieve their softening temperature at lower temperatures. A mechanical device, such as a roll, can be used to pick out softened material.

d) Sorting of plastics with spectroscopic devices. Identifying and separating plastic granules in an automatic recycling line.

The spectroscopic method typically requires a very low quantity of contaminants, such as some percent.

e) Separation based on selective dissolution in a solvent, e.g. impurities from PVC.

A filtration in the solvent phase allows to eliminate the impurities (rubber, glass, metals, fibers, labels, other polymers…).

An effective separation will be achieved in some cases especially if the waste consists only of two materials significantly differing from each other in some property.

The separation of a conglomerate of materials is much more difficult and cost-intensive and this will be mostly the case for the end of life polymeric electrical insulating materials.

The presence of metal and other conducting contamination (e.g. carbon) will pose a specific problem with regard to the reuse of the recyclate material as an electrical insulation material.

5.3 Recycling of the polymeric materials in WEEE

Most of the end of life polymeric electro-insulation materials will be included in the WEEE (Waste Electrical and Electronic Equipment).

The collection, processing and recycling steps of the WEEE could be as follows:

a) Collecting Electric and Electronic (E&E) equipment via permanent drop-off locations, waste collection networks etc.;
b) Evaluating E&E equipment re-use potential. They can be refurbished or donated if possible;
c) Disassembly of hazardous components such as batteries. Some valuable parts or components might also be recovered;
d) Metals recovery and recycling;
e) Other materials including the polymeric electro-insulation materials.

Typical compositions of some types of WEEE are shown in Table 1.

Table 1 – WEEE typical composition [13], [14]

	Brown goods %	Data processing & office equipment %	White goods %	Printed circuit boards %
Polymers	26	13	7	30
Ferrous	35	40	44	
Non-ferrous	26	30	32	30
Glass	4	5	4,5	30
Wood	1	1	1	
Other	8	11	11,5	10
Total	100	100	100	100

It shows a very high mass proportion of metals – that are rather easily recovered and recycled after simple mechanical separation processes.

After metals have been sorted out, the plastics will be in the form of granules and might remain mixed with glass, wood, metal contaminations and other remaining materials.

The estimation of the plastics fraction in the WEEE was 17,7% for a total of 4 395 000 tons in Western Europe in 2000.

There are technical constraints involved in determining the most appropriate polymers recycling chain. For any recycling process, the feed materials need to be de-dusted and hazardous materials need to be removed.

A presorting of the WEEE can sometimes be of interest to simplify the separation operations and to recover high quality recycled polymers with a lowest global cost.

Besides mechanical recycling there are methods of chemical or feedstock recycling residues that are more complex waste than WEEE. Such methods could be more expensive than mechanical recycling routes for certain sufficiently pure polymer wastes.

However, they offer a solution for the most complex mixed plastics waste treatment.

In the future, it might be advantageous to combine several treatment methods to recover several metals and polymers gathering the most economical and environmental value from the WEEE waste streams.

Detailed and in-depth research and development work has already been carried out and will clearly continue in the future in order to increase the performances of the different recycling methods.

6 Material factors

6.1 General

Product committees should not compromise on safety requirements. When considering that the products are allowed to contain recycled plastics, recycled materials and end-products will have to comply with the requirements as specified in the relevant end-product standards.

6.2 Mechanical properties – Tensile strength and toughness

Strength is a mechanical property. It is outlined in ISO 527 and ISO 179.

In general, recycled polymers have inferior mechanical properties than the same polymers in virgin form. Examples are shown in Figures 3 and 4.

Therefore, recycled polymers are usually used in mixtures of recyclate and virgin polymers. In this case, the ratio of recyclate-to-virgin components is a major parameter to manage, in order to achieve specified level of performance [1]. Co-injection (sandwich) moulding and coextrusion employing virgin polymer for the outside and recycled polymer as the core material of a core-skin structure is also used.

The impact of recycling on the mechanical properties of polymers may be seen especially from the tensile strength and the toughness characteristics.

Tensile strength [2] is the ability of a material to withstand tensile loads without rupture when the material is in tension.

Toughness is the ability of a material to withstand crack propagation. A material in which the cracks easily propagate when mechanically stressed is brittle. Toughness indicates the ability of a material to absorb energy without rupture.

Toughness is an important material property [3]. Different types of toughness measurements may give different or even contradictory test results. It is recommended that the toughness properties should be evaluated by two or more complementary methods. The J-integral method and the common Charpy impact test or Izod impact strength method constitute such a pair.

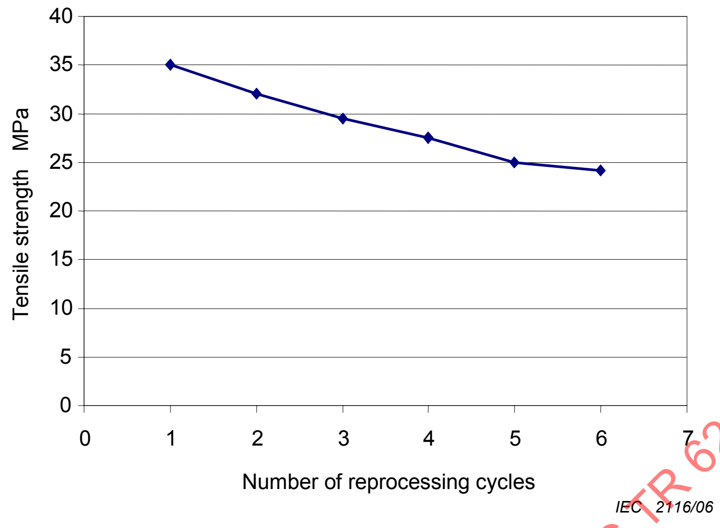


Figure 3 – Tensile strength of reprocessed material

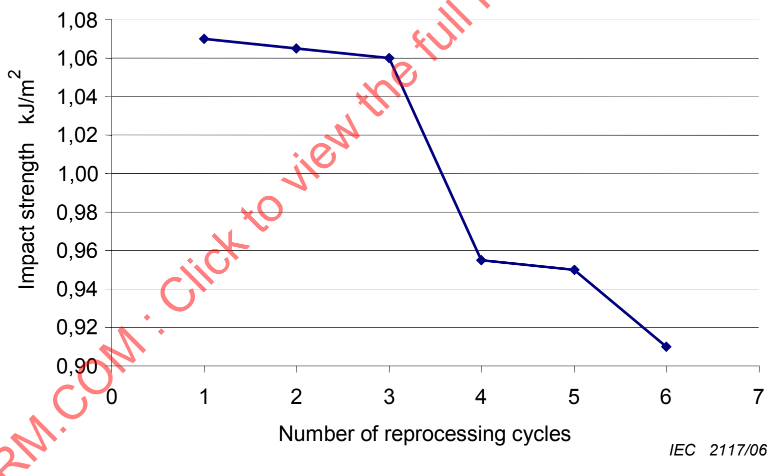


Figure 4 – Izod impact strength of reprocessed material

Figures 3 and 4 show the mechanical degradation as a result of reprocessing [4].

When considering the effects of polymer recycling it should be emphasised that for some materials the mechanical properties such as impact strength and resilience are most likely to be compromised. Non-impact mechanical strength on the other hand may well be enhanced.

6.3 Thermal endurance

Thermal endurance is assessed by several test methods including the IEC 60216 series. Service degradation over the long life of products is simulated via moderately elevated test temperatures to produce a manifestation of thermal degradation in a reasonable though protracted test time.

The relative thermal endurance index (RTE) as defined in IEC 60216-5 is the numerical value of the temperature in degrees Celsius at which the estimated time to endpoint of a candidate material is the same as the estimated time to endpoint of the control material at a temperature equal to its assessed thermal endurance (ATE) which is the numerical value of the temperature in degrees Celsius, up to which the control material possesses known, satisfactory service performance in the specified application.

It can be expected that at this temperature a class of critical material properties is acceptably stable over the full service life of equipment. As a measure of thermal stability, thermal degradation may well be enhanced by moderate additional heat histories; i.e. as a measure of sensitivity to relative property changes, thermal degradation will naturally be decreased if material property is stabilized to lower performance levels by the additional heat histories of material recycling.

Thermal analysis, especially differential scanning calorimetry (DSC), to measure the remaining thermal stabilization of a material after ageing, allows evaluating the so-called Oxygen Induction Time or Temperature OIT/OITP, according to IEC 61244-3.

6.4 Flammability/ignitability

All thermoplastics, flame retardant and non flame retardant, can be recycled. Recycled materials may have different fire behaviour compared to the virgin materials they are derived from.

6.5 Arc resistance

This method is intended to differentiate, in a preliminary fashion, among similar materials with respect to their resistance to the action of a high-voltage, low-current arc close to the surface of insulation, in tending to form a conducting path therein or in causing the material to become conducting due to the localized thermal and chemical decomposition and erosion. A test gives a relative measure of the tendency of an insulator to become surface tracking due to repeated low current arc contacts under high voltage.

6.6 Comparative Tracking Index

IEC 60112 is the preferred method and uses a “contaminating” solution dropped between energized electrodes at the specimen surface, intended to accelerate the development of a self-propagating and self-enhancing tracking.

Ultimately, while either in service or while testing, tracking will develop with a sufficient quantity of partially conducting contaminant, from either or both degraded material (e.g. material burned or degraded from exposure to arcing, etc.) or externally deposited material (e.g. dirt, dust, salt, moisture, etc.).

In service tracking failure is a likely source of ignition and fire since the partially conducting track has a resistance high enough to prevent activation of circuit protective devices, yet low enough to produce considerable electrical heating.

Subtle changes in the surface material are known to have profound effects on tracking resistance. A recycle process will expose the bulk of material to additional thermal cycles, and may influence material degradation leading to the formation of a track.

6.7 Insulating performance (volume resistivity, dielectric strength)

The insulating resistance of solid electrical insulating materials is commonly measured using test methods outlined in IEC 60093. In many end product applications the insulating resistance of the polymeric material is significantly higher than the minimum necessary for the safe operation of the device. Recycled polymeric materials would be expected to exhibit insulating resistance similar to the virgin material. Some degradation is possible depending on the impurities in a particular recycle stream; however, conductive impurities are to be avoided. Some polymeric materials, designed specifically for applications requiring higher conductivity, are of a particular concern regarding insulating resistance after recycling.

6.8 Weatherability – UV-resistance

The performance of all polymers is affected by UV radiation. UV radiation acts upon the molecular structure of the polymers with the result of changes in optical and mechanical behaviour or properties. Long-term exposure to the weather can be specially harmful to many materials. With respect to most plastics, ultraviolet (UV) light from the sun is the major culprit. Other environmental factors, such as moisture and extreme temperatures, simply make the problem worse. Long-term, continuous outdoor exposure of most unstabilized thermoplastics normally results in changes in colour and other physical properties. These changes can usually be measured quantitatively as indicators of a material's long-term weathering stability:

– colour and haze – clear materials may develop a yellow cast and a white surface film;
– impact strength – tough resilient materials may become brittle.

Long-term impact strength may be critical, considering factors such as wind load and low temperatures.

NOTE The performance of most thermoplastic materials depends largely on their molecular structure. A tough, material will generally exhibit a structure in which the molecules are arranged in long, chain-like configurations. UV light causes the molecular chains to break up into shorter chains. This process, known as photo degradation, results in molecular structure more typical of brittle materials.

Product Committees should make sure that the degradation by UV radiation of the recycled material does not exceed their requirements.

7 Design factors

7.1 Ease of dismantlement

Optimum recycling of thermoplastic polymers is normally only possible if they belong to the same polymer type. To guarantee this without expensive dismantling and sorting, only a single type of polymer should be used in one product where possible. Recyclable waste and components should if possible be sorted according to moulding compounds and colours. In most cases, this will not be completely possible. If two incompatible polymers are mixed together, a process called phase separation occurs. Distinct regions of each polymer will be visible under a microscope or the naked eye; no chemical bond exists between these materials. To be able then to recycle the mixtures of polymer which arise whilst at the same time ensuring that completely worthless elements are not obtained, the selected combinations of polymers must to some extent be miscible with each other [12].

In order to reprocess materials and retain good properties for a new product, well sorted materials are needed rather than a blend of a number of immiscible plastics. Before moving on the process of sorting one should visualize the most important points[5]:

- processing causes degradation of the material as a result of heat and shear;
- mechanical actions such as grinding also exert shearing stresses and even chemical modification;
- plastics have different melting points, different softening temperatures and different temperatures for the onset of thermal degradation;
- immiscibility of plastics with each other, leads to deterioration in mechanical performance;
- good dispersion and homogeneity are required.

Partially compatible polymers can be homogenized by so called compatibilizing agents or polymers. Most often the balance of material properties, part design, production process, product performance, dismantlement/recycling processes, and finally product and life cycle costs, is a compromise where any change influences all the other aspects.