LONGEVITY AND ECOLOGY OF POLYOLEFIN ROOF MEMBRANES

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After decades of successful application in underground waterproofing, polyolefin membranes are beginning to have an impact in roofing. For some membranes, this development has been made possible by the introduction of new, flexible raw materials. For other membranes, the formation of polymer alloys by choosing appropriate copolymer raw materials leads to very flexible polyolefin compounds. Common designations for these products are thermoplastic polyolefins (TPOs) in North America and flexible polyolefins (FPOs) in Europe.

The flexibility of these roofing grade polyolefins is achieved by internal flexibilization. As a consequence, no plasticizer can be lost during service life. This fact and the polyolefinic material base provide the membranes with unique properties, such as excellent chemical and microbiological resistance, ease of application, and pronounced longevity. Respective data are given in the paper.

The lifetime of polyolefin roof membranes, as discussed in the paper, depends strongly on the proper ultraviolet (UV) stabilizer package in conjunction with a suitable flame retardant. Commonly used flame retardants are bromine compounds. Investigations have shown that bromine compounds can have an adverse effect on the long-term UV stability of the membranes. Membranes with brominated flame retardants can exhibit good UV stability over a certain period of time but suddenly deteriorate quite dramatically in accelerated aging. Properly stabilized products that don't use brominated compounds have a markedly higher UV stability. Thermal stability and surface temperatures affect the lifetime of roof membranes, as well. The paper explains how positive effects in this field can be achieved.

Another outstanding feature of polyolefin membranes is their ecological profile. The results of an ecological study investigating the impact of flexible polyolefin roofing sheets on the environment are presented. The study takes into account all steps of the material's life cycle, ranging from the preparation of the basic raw materials through production, application, and service life to recycling.

KEYWORDS

Durability, ecology, flexible polyolefins, FPO, lifetime prediction, polyethylene, polypropylene, recycling, roof membranes, thermal stability, TPO, stability against microorganisms, sustainable roofing.

INTRODUCTION

People involved in the construction and use of buildings have begun to develop an increased awareness of the environmental impact that building materials and their applications have. The choice of building materials is no longer based solely on traditional considerations such as economy, functionality, appearance, and practicality. Factors such as the ecological profile of primary materials used, recycling and disposal possibilities, and potential health hazards for construction workers or residents now play a role, as well.[1] State of the art product development thus demands that ecological criteria are treated on equal terms with the traditional considerations. In order to face this ecological challenge, the family of polyolefins represents a promising alternative to conventional polymeric roofing materials.

Polyolefin membranes have a long history in waterproofing applications. Numerous waste disposals and open cut tunnels have been successfully lined with polyethylene-based sheets. Although they have generally performed well, certain material properties, especially their stiffness, made them unsuitable for use on roofs. Advances in polymer material and processing technology over the past few years, however, have led to the development of new polyolefin roof membranes. They allow the many advantages of products based on polyolefin raw materials to be used in the rooftop environment.[2]

MATERIALS

In 1991, polyolefin roof membranes were introduced to the market. These products are known in Europe as FPOs, whereas the designation TPO is common in North America. Significant advantages include bitumen and polystyrene compatibility, extremely good low-temperature flexibility, excellent puncture resistance, and high welding speeds. Both designations, FPO and TPO, will be used as synonyms in this paper.

Two basically different types of FPO roof membranes are known:

- polypropylene- (PP-) based membranes
- polyethylene- (PE-) based membranes

The type of base affects the various characteristics of the membranes. Generally, the PE-based types are more flexible and, therefore, easier for the roofing contractor to handle. PP-based materials are somewhat stiffer but show, on the other hand, better mechanical properties, especially at higher temperatures.

Polypropylene- (PP-) based membranes.
The raw materials consist of so-called reactor polymers. In the patented Catalloy process,[3] thermoplastic polypropylene is blended on the plant level in the reactors with thermoset polymers to achieve the desired end properties, such as high flexibility and mechanical strength.

To date, only raw material produced by one supplier is known to be used for roofing applications. However, several

U.S. and European manufacturers are producing roof membranes with these materials by extrusion or calender technology. Unreinforced products and membranes with polyester fabric or fiberglass mat reinforcement or a combination of both are available.

Several million square meters (several ten millions of square feet, estd.) of such types of products have been used to cover roofs in North America and in Europe. First applications became known in the United States in 1991 and in 1994 in Europe.

Polyethylene- (PE-) based membranes.
For PE-based membranes, special grades of copolymers and terpolymers (acetates, acrylates, or octene) of polyethylene are blended during the membrane manufacturing process to form a highly flexible polymer alloy. First test installations with this kind of roof membranes date back to 1988 in Europe and to 1992 in the United States. Full-scale market introduction took place in 1991 in Europe. To date, several suppliers of polyethylene-based FPOs are known in the European marketplace. In total, just over 10 million m² (100 million square feet) have been installed since 1991. Applications with PE- and PP-based FPO/TPO roof membranes range from gravel-ballasted systems and green garden roofs to mechanically fixed smooth surface systems. Adhered applications of such materials are not widespread.

Membranes for mechanically fixed roofs are usually reinforced with polyester scrim or fabric to provide the membrane with the required tensile and tear properties. One membrane contains a fiberglass mat reinforcement with additional polyester reinforcement to ensure thermal dimensional stability and minimal shrinkage (see Figures 2 and 3), as well as high tensile and tear properties.

Incorporation of this fiberglass mat fleece into these polyolefins is not possible by conventional calendering procedures. Therefore, an appropriate technology, which is referred to as extrusion coating as shown in Figure 1, was developed.

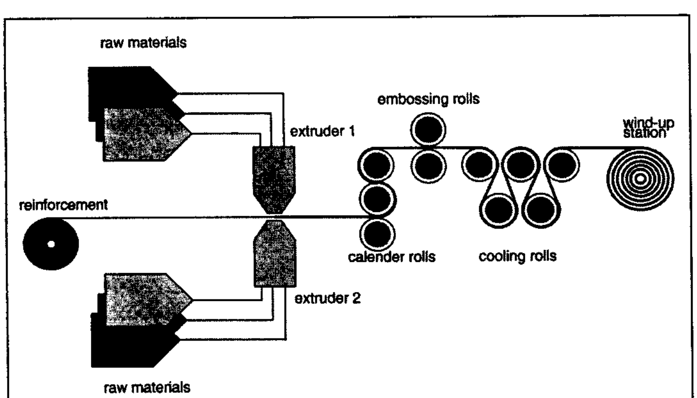

Figure 1: Scheme of extrusion coating process for FPO membranes.

PROPERTIES OF POLYOLEFIN MEMBRANES

Polyolefins generally have somewhat of a considerably high linear thermal expansion coefficient. Hence, unreinforced membranes tend to curl when unrolled and, subsequently, become quite wavy when heated by sunlight. This renders the welding of the seams quite difficult. It is, therefore, highly advisable to incorporate a fiberglass mat into the membranes to reduce the thermal expansion and contraction behavior by a factor three to four, as shown in Figure 2.

The linear thermal expansion coefficient of unreinforced PP-based FPO is lower than for the corresponding PE type. However, the fiberglass mat brings the thermal dimensional behavior of both material bases to the same level.

Roof membranes generally contract upon cooling. This induces contraction forces to membrane perimeter fixations. An additional benefit of the stabilizing fiberglass mat is the reduction of these forces by the same factor as above. Not only is the reversible thermal expansion and contraction behavior positively influenced by the fiberglass mat, but more importantly, the irreversible shrinkage that is inherent to all kinds of roof membranes upon the first solar heating after production is practically eliminated. This first solar heating corresponds to the ambient conditions during installation. Figure 3 illustrates how the fiberglass mat stabilizes a membrane. With a fiberglass mat, the dimension change is limited to about 0.1 percent, whereas for the unreinforced membranes, the dimensional change upon first heating can exceed 0.5 percent and reach up to 2 percent.

One of the most important features of polyolefin membranes is that unlike other thermoplastics, such as PVC, which require the addition of a plasticizer to the base polymer during membrane compounding, FPOs are "internally plasticized" during the raw material production. By the use of comonomers, the FPOs are inherently plasticized because

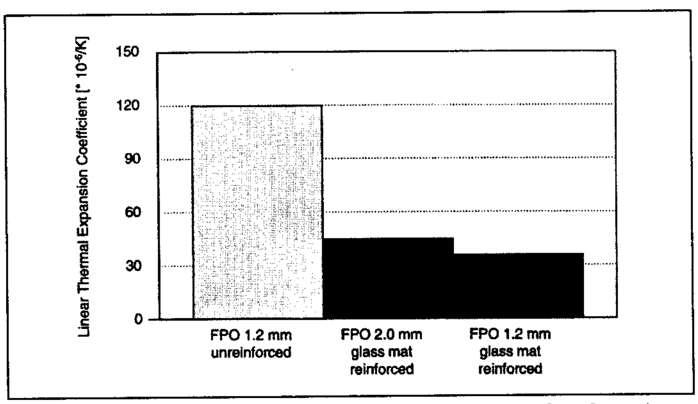

Figure 2: Comparison of dimensional behavior of reinforced and unreinforced FPO membranes: Linear thermal expansion coefficient between -20 and 70°C (-4 and 158°F).[4,5]

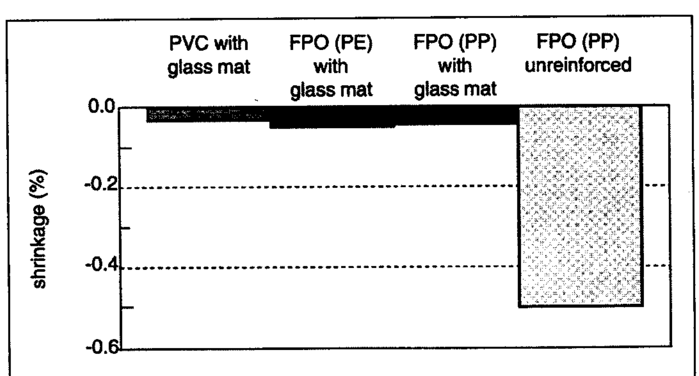

Figure 3: Thermal dimensional stability (initial dimension change after heating) according to SIA 280/36 of various roofing membranes of 1.2 mm (47 mil) thickness.

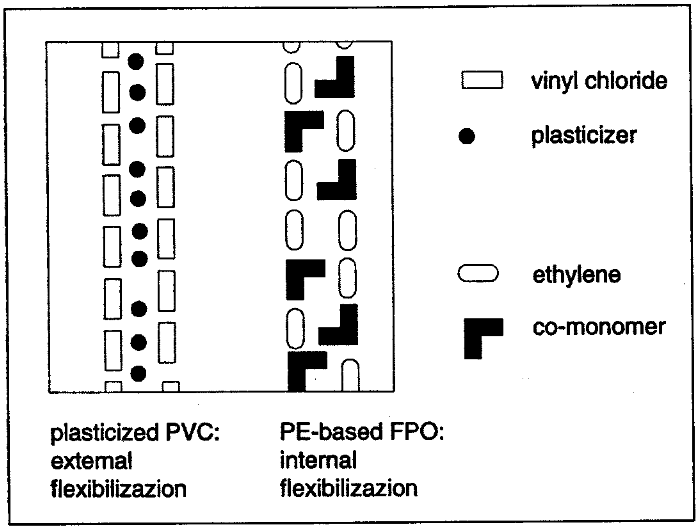

Figure 4: Schematic illustration of internal and external polymer flexibilization.

these comonomers create an increased free volume and they decrease the crystallinity of pure polyethylene or polypropylene. Therefore, they cannot lose their plasticizing agents, a key factor in the aging of a number of thermoplastics.

Polyolefin materials are generally known to have excellent chemical and biological resistance. As an example, Figure 5 presents the results of a 12-month soil burial test. This test is used to evaluate a roof membrane's resistance against microorganisms and, thus, its suitability for gravel-ballasted applications. A very aggressive soil is used in which a cotton strip loses 75 percent of its tensile strength within one week of being buried. The tested FPO membrane showed an extremely low weight change that stabilizes after eight months. This is a clear indication that polyolefin roof membranes are well-suited for gravel-ballasted roofs, a fact resulting from the internal flexibilization and the absence of plasticizers. This outstanding microbiological resistance is accompanied by a high resistance to chemical media, such as acids and bases.[4,5]

As briefly discussed, the seams of FPO membranes are heat-welded. Other seam technologies, such as solvent welding or adhered seams as in conventional plastic membranes, are not used with FPOs. FPOs need a relatively low welding energy and hence can be welded at unusually high speeds as shown in Figure 6. Although air heated to 450°C (842°F) is used during the welding process, there is no polymer degradation. In

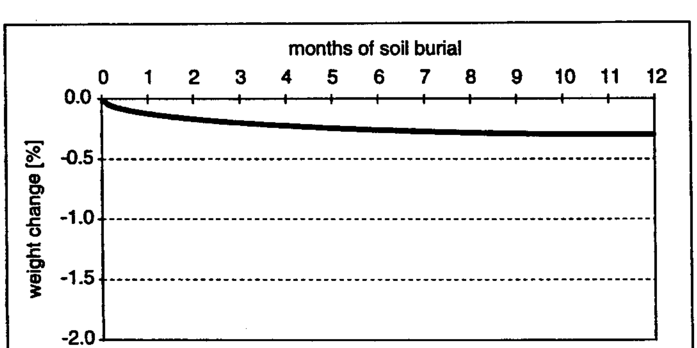

Figure 5: An FPO membrane in the soil burial test according to DIN 53739 method D.[7]

fact, the membrane surface never heats up to more than about 200°C (392°F), and the polymer is heat-stabilized.

LONGEVITY

Durability is the key issue for a roof membrane. Accelerated aging tests in the laboratory have been developed and standardized in order to allow an assessment of the design service life after testing times of only one or two years (some examples are the test methods listed in References 6 through 11). One of these accelerated aging procedures consists of exposing the samples to a combination of UV radiation, water, and elevated temperature. Figure 7 presents the results of such an accelerated UV aging test performed on an FPO membrane (PE-based).

The test was carried out using UV-B-313 fluorescent lamps with a cycle of six hours of UV irradiation 60°C (140°F) and two hours of water vapor condensation 50°C (122°F). The testing conditions were chosen according to References 6 and 10. The elongation at break and visible changes of the samples were periodically measured. The FPO membrane tested exhibits no crazing and only a minor decrease in elongation at break of 6 percent after 14,000 UV hours (26 months' testing time). A requirement of the Swiss standard SIA 280, using the less destructive fluorescent lamps UV-A-340, is the absence of crazing after 5,000 UV hours. The fact that the test results for the tested FPO membrane lie far above the requirement of the standard suggests an extremely long service life. Similar long-term behavior can be obtained for PP-based FPOs with a somewhat higher amount of UV stabilizers than for the PE-based type. To ensure a com-

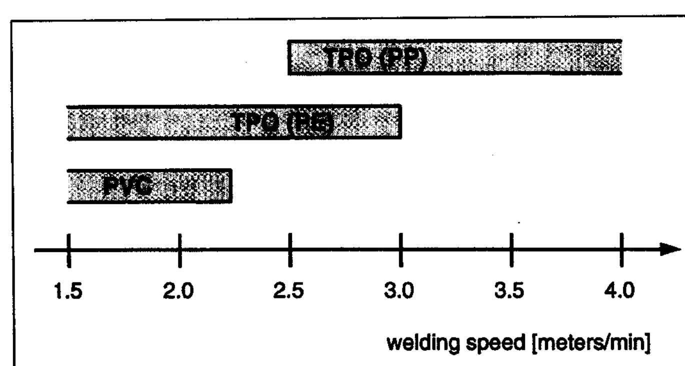

Figure 6: Comparison of welding speeds of PVC, PP-based FPO, and PE-based FPO. Data were measured at 450°C (842°F) hot air temperature at the nozzle with a commonly used automatic welding machine.

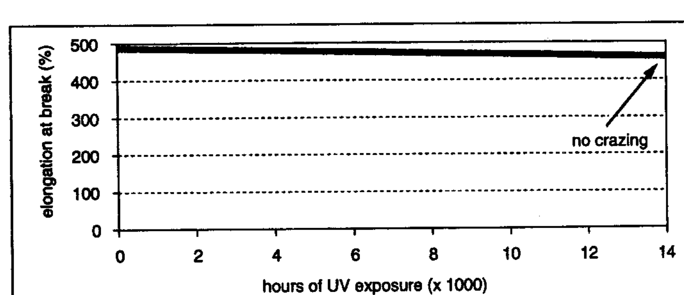

Figure 7: Accelerated UV aging of an FPO membrane (PE base, color: beige) with UV-B-313 fluorescent lamps.

parable lifetime, however, bromine compounds must not be used in the formulation (see below).

In Figure 8, a lifetime prediction based on the accelerated aging data of a PE-based FPO and using a linear model is calculated. It is compared with data gathered regularly every year from samples of a test roof installed in 1988. After eight years of field experience, the measured data confirm so far the lifetime prediction for this particular product. After this time of experience, there is no evidence for any change of aging mechanism during service life (i.e., the linear prediction model seems to be correct).

Well-formulated PVC roof membranes have been proven to have a service life of more than 20 years,[12,13] in cases of exposed applications, more than 30 years.[14] According to the accelerated laboratory aging tests, the investigated FPO product exhibits characteristics at least equal to a well-formulated PVC.

This excellent UV stability of polyolefin materials is made possible by the use of hindered amine light stabilizers (HALS). A good UV stability is a main requirement for membranes in mechanically fastened systems, because in this application, they are not protected by ballast. On the other hand, very demanding fire regulations exist for these applications where the roof membrane is the directly exposed top layer. The easiest way to fulfill the requirements of severe fire tests without a ballast layer is to use bromine compounds as flame retardants. However, the HALS UV stabilizers can be degraded by halogenic materials such as chlorinated or brominated compounds. It is a fact today that many commercially available TPO membranes have bromine-based flame retardant systems. The option to avoid the risk of adverse interaction between the flame retardant and the UV stabilizers is the use of mineral hydrate flame retardants. Additionally, chlorinated and brominated compounds are not regarded as environmentally friendly, in contrast to a mineral hydrate flame retardant.

Figure 9 shows that the UV stability of polypropylene-based membranes with bromine flame retardants is significantly lower than that of membranes with mineral hydrate flame retardants. In fact, the UV stability of the former is lower than that of a membrane designed to be protected from direct exposure to sunlight by gravel covering. Especially dangerous seems to be the fact that the bromine-containing products show a satisfactory behavior for a certain period of time but are subject to dramatic crack formation (Damage Level L4) in a rather short time after initial crazing (Damage Level L1) has occurred. Conclusively, lifetimes that correspond to the prediction according to Figure 8 cannot be expected of FPO products containing brominated flame retardants.

Another aspect affecting the lifetime of roof membranes is temperature. Assuming that the decay of any polymer would

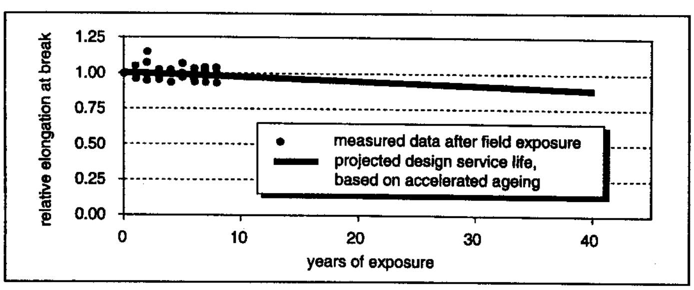

Figure 8: Comparison of lifetime prediction and field data of an FPO membrane gathered over a period of eight years.

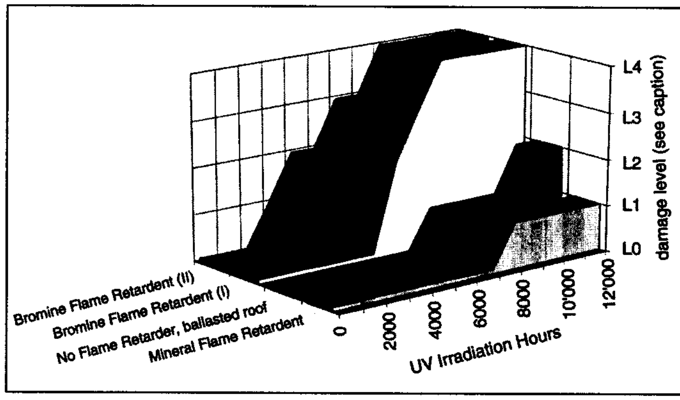

Figure 9: Resistance to UV aging: Crazing and cracking of PP-FPO membranes. Same testing conditions as in Figure 7. Designation of damage level: L0—No crazing; L1 Faint surface crazing, visible at ten times magnification; L2—Same as L1, crazing more pronounced; L3—Surface cracks visible to the naked eye; L4—Deep cracks visible to the naked eye. Products containing brominated flame retardants show no cracks during the first 2,000 hours, but then develop deep cracks within short time. The product containing a mineral hydrate flame retardant shows only faint surface crazing after 12,000 UV hours.

occur through the degradation of the polymer chains, which is a chemical process, reducing the temperature by 10°C (18°F) would reduce the decay rate by a factor of two to three according to Arrhenius law. Thus, reducing the surface temperature of a membrane can result in an increased life expectancy. Figure 10 shows how the summertime surface temperature of roof membranes can be influenced by the choice of colors (i.e., the choice of pigments). The lighter the color, the lower the surface temperature. Under the measuring conditions, black roof membranes reached peak surface temperature of 90°C (194°F). This temperature can be decreased by 30°C (54°F) or more by using light colors, such as white, beige, or light gray. The most favorable conditions are present with the high reflectivity of white surfaces. Thus, light membrane colors can help positively in increasing the product lifetime. However, no quantitative data are available on this subject. A light-colored surface, however, does not eliminate the risk of severe UV degradation when halogens are used in the polyolefin membrane.

ECOLOGY

In some countries in Central and Northern Europe, ecological aspects of building materials have gained considerable

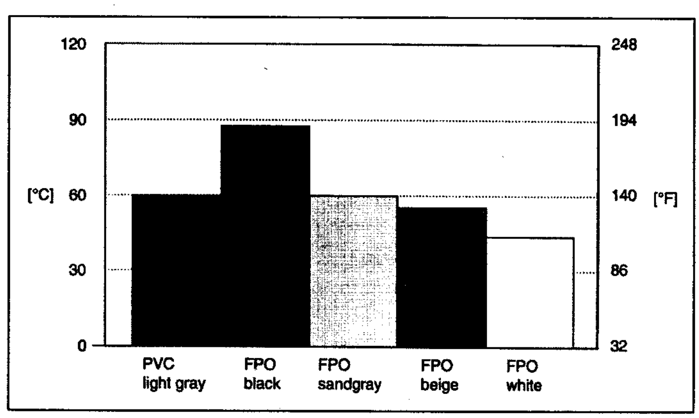

Figure 10: Influence of membrane color on surface temperatures, measured upon direct irradiation by sunlight (June 1996, Central Europe).

importance. Designers in particular in these countries emphasize the importance of using ecologically clean building products.[15]

Basically, all manmade materials are environmentally intrusive to some degree. Everything man exploits, transports and produces has an impact on the planet because raw materials and energy are needed for doing so. Additionally, at the end of their service life, products and buildings should be reused or recycled. However, the extent to which a given product affects the environment can vary widely. It is, therefore, imperative to control the energy and material balance, from raw materials exploitation and processing through transportation, production, application, service life to recycling such that the impact on the earth is minimized. An excellent overview on the salient point in sustainable roofing has been given by Smith.[1] For the environment, the total energy and mass balance is important and not just single isolated positions. From this point of view, the following requirements for any material are essential:

- no toxic effects to life and the environment
- low amount of material used
- longevity
- low energy demands
- ease of reuse or recycling

Ecological Balance Study of FPO Membranes

The environmental department of the largest Swiss institute of engineers and planners has carried out an ecological assessment of PE-based FPO membranes containing no halogenated flame retardants.[16] As explained above, the entire life cycle of the membrane has been taken into account (i.e., the process chains of gaining and producing the raw materials, the production of the membranes, their application, their service life, and recycling). Additionally, the fire hazard has been investigated.

Service Life

As a result of all the difficulties encountered during the collection of data and the interpretation of the many factors in an ecological balance, one often forgets that the service life has a decisive influence on the ecological assessment of a product.

A product pollutes the environment to a certain extent throughout its life cycle. On the basis of experience, the largest amount of impact occurs during production and disposal. Not only the degree of impact is of importance, but also the time span over which it occurs (i.e., environmental impact per unit of time).

The longer the service life of a product, the lower the environmental impact per unit of time. Thus, if the time span between production and disposal is increased, then the environmental impact per utilized unit of time (e.g., per annum) is reduced in corresponding proportion.

On the basis of tests carried out[16] and the experience acquired to date (cf. Figure 8), the assessment report says that the investigated FPO membranes can achieve extraordinary long life cycles. As a result, the environmental impact over the life span of the product is greatly reduced in comparison with products that have a lower durability, even without any ecological improvements in the polymeric roof membrane.

Additionally, an increased life span also serves to conserve resources (e.g., petroleum) and to reduce the burden on waste disposal facilities.

Primary Materials

The primary materials and additives for FPO membranes are not produced by the membrane manufacturer, but in prior process chains. Detailed information on the individual manufacturing processes in these prior process chains is not available, if for no other reason than the suppliers must protect their manufacturing secrets. Thus, only limited statements are possible concerning the manufacture or production of any components (i.e., if critical process steps are involved with regard to the environment or industrial hygiene).

The investigation was thus limited to an assessment of the compounds resulting as products of the prior process chains. Product information from the manufacturers, especially the relevant safety data sheets, as well as rough basic considerations on grounds of the molecular composition of the individual primary materials, served as a basis for this investigation.

The raw material and all the additives are nonhazardous (i.e., when stored and handled appropriately, they can be assessed as harmless both toxicologically and ecologically). All of the components have been on the market for quite some time, and thus, no unknown hazards are to be expected. All the products are used in the form of granules or powder. Thus, the risk of accidental contamination of the environment during storage and transport is low (no spilling of liquids). Toxicologically critical materials or halogenated compounds are completely absent.

The ecological advantages of the investigated PE-FPO and similar raw materials can be summarized as follows:

- no use of any heavy metals
- no use of any ecologically questionable flame retardants, such as halogenated (e.g., brominated) compounds
- absence of plasticizers

Manufacture of the Membrane

During the actual manufacture of the roof membrane, two process steps are especially relevant to the environment.

- Compounding (i.e., the mixing of the various primary materials). When drying the compound during granulate manufacture, dust emissions and waste water pollution result.
- Heating of the compound during the extrusion coating. During this process, the release of volatile components or thermal cleavage products is to be expected.

It is not possible on the basis of theoretical considerations to make a prediction regarding the expected emissions (what, how much) for compounding or extrusion coating. Thus, various measurements were made:

- dust measurements in the compounding room
- analysis of waste water samples from the compounding unit
- of the gaseous emissions resulting during extrusion coating

At three different locations, readings were taken for the amount of fine dust pollution [0.5 to 0.7 μm (0.02 to 0.03 mill)] as well as for the total amount of dust pollution [>0.5 μm (>0.02 mill)]. The measured concentrations were approximately 10 to 50 times below the corresponding Swiss Threshold Limit Values (TLV*). Thus, the concentrations at the work place can be assessed as harmless. Consequently, no protective measures, such as breathing masks, are necessary when mixing and transferring the substances.

The dust emissions that enter the environment through the ventilation system were also investigated. The Swiss regulation concerning air pollution control (LRV) sets the limiting values. The dust concentrations measured are many times lower than the permissible LRV values. Thus, an adverse effect on the environment through the generation of dust can be ruled out.

To assess the waste water resulting from the drying of the compound, the pH value, as well as the concentrations of dissolved organic carbon (DOC), aluminum, and titanium, were determined. The waste water shows only a slight pollution. With regard to the parameters analyzed, the concentrations are such that, according to the Swiss regulation concerning the treatment of waste water, they comply with the conditions stipulated for direct flow into natural water resources. The waste water is, nevertheless, sent to a purification plant.

The emissions during extrusion coating were investigated directly at the source (nozzle) (i.e., the point where the concentration is at its highest). The spectrum of the emitted substances was determined by means of a gas chromatography—mass spectroscopy (GM—MS) analysis. In addition, the total hydrocarbon concentration of the emission and the background values were measured and the nitrogen oxide and formaldehyde emissions were determined by means of Draeger tubes. The analysis showed that the threshold limit values were not exceeded. No toxicologically critical emissions were detected. A complete test report is available in Reference 16. All the identified substances are, according to Swiss standards, either exempt from toxicity class or comparatively nontoxic (toxicity class 4, the second lowest toxicity class in—this class products can be bought freely by anyone; the vendor needs a registration). Here too, environmental pollution as a result of the waste air from the production can be ruled out because the concentrations of the substances lie far below the limits of the LRV. Thus, no waste air filters or waste air treatment facilities are required.

The investigations of the ecological and industrial hygiene effects of the FPO membrane during the complete life cycle have not revealed any problem areas worth mentioning. In the individual segments, the following picture emerged:

Installation/Maintenance

An analysis of a welding process under normal conditions showed that far lower substance concentrations were emitted directly next to the hot air nozzle than during the extrusion coating. The identified components correspond largely with those arising during production. The measured maximum concentrations lie at least 100 to 1,000 times below the corresponding threshold limit values. Moreover, the substances emitted during welding are scarcely critical with regard to toxicology and potential environmental pollution. Thus, no specific work protective measures are necessary during installation or maintenance. One can even work in closed rooms (e.g., during training courses) for a long period without any ventilation.

* The Threshold Limit Value is the highest permissible average concentration in the air of a foreign substance at the work place that does not endanger the health during a daily exposure of eight hours over longer periods for the overwhelming majority of healthy workers.

Utilization

During the utilization phase, the polymeric roof membrane is subjected to a long-term exposure to light, water, heat, microorganisms, and mechanical stress. These factors can cause certain components (such as pigments or additives) to be leached out or to be released into the air. To assess the ecological effects of these factors during the utilization phase, it is necessary to have information on the type and the amount of emitted substances, as well as on their levels in the environmental components (water, soil, dirt). These questions can only be answered to some extent theoretically. Thus, laboratory tests were conducted, partially under extreme conditions. It was not possible to determine the emissions directly because the resulting migration (amount per unit of time) is exceedingly small even under extreme conditions and an unassessable amount of various substances (potential degradation and transformation products) would have to be analyzed.

Under the most extreme conditions during accelerated laboratory aging, an insignificant weight loss can be observed. The maximum loss detected during all the aging tests was less than 0.5 percent. It can best be explained by a partial leaching out of the stabilizers. An ecological assessment of the entry of stabilizers into the environment depends mainly on the migration (amount per time) as well as on the degradability of the substances released into the environment. Because of the very low toxicity of all the primary materials as well as extremely low migration rate during normal utilization, an adverse effect on the environment during the utilization phase can in all probability be excluded despite the very low biodegradability of the stabilizers.

Recycling

Every product results in waste. In most cases, waste material is already produced during manufacture and processing. Also, refuse is normally produced at the end of a product's service life. However, for many types of waste material, reuse or recycling can take the place of disposal. Usually, this decreases environmental impact. FPO membranes, as thermoplastic materials in general, are basically very well-suited for recycling in all life cycle stages during which waste material is produced.

Production scrap (start-up scrap, trimmings, etc.) is already being completely recycled. In Europe, refuse from building sites is being also collected and reused in the production process. Scrap and refuse are returned directly into the production of the new membranes and are used there as prime raw materials.

The question of recycling old membranes after their service life has been proven to be solved. In smaller amounts, recycling material can be incorporated in the normal production process. Larger amounts of old material can be used to fabricate protection sheets used, for example, in tunnel lining. At this time, the available amount of recycling material is so low that mainly new raw material must be used for the production of these protection membranes.

Disposal

To assess the behavior of FPO membranes during incineration, an analysis of material flows based on the composition of the membrane was undertaken.[16] This resulted in material distribution diagrams, which show how the individual substances are distributed among the various products (slag, filter dust, stripped gas, waste water, and flue gas stripping sludge) during the incineration, the flue gas stripping, and the treatment of the incineration and flue gas stripping residues.

The incineration of FPO membranes in a waste incineration plant can be assessed as uncritical from an ecological point of view. As during all incineration, essentially carbon dioxide, water, and heat are produced. The inorganic additives of the polymeric roof membrane hardly volatilize during the normal incineration temperatures and, thus, do not cause any relevant air pollution. Instead, they are transformed almost completely into slag in the form of oxides, where they can be immobilized by means of a corresponding treatment and subsequently disposed of in suitable landfills. In comparison with average residential refuse, FPO membranes actually form less toxic agents during the incineration and, therefore, cause less environmental pollution. No stable toxic compounds are produced during incineration.

From an ecological point of view, the dumping of polymeric materials that are rich in energy is rather pointless. Rather, the thermal utilization of the energy contained in the petroleum derivatives of the polymeric roof membrane should be attempted. However, if in spite of this the FPO membrane is dumped, ecological problems can in all probability be excluded because of the harmless raw materials and additives. Moreover, the FPO membrane remains, to a large extent, inert under test conditions (buried in soil) (i.e., decomposition caused by microorganisms hardly takes place). Quantitatively, the emissions from FPO membranes will thus be extremely small, but they will extend over a long period.

Ecological Balance Study of Roof Systems

From the point of view of the building owner, not only is the environmental relevance of a single building product interesting but so is the impact of the installed systems. For this reason, recently published ecological balance studies[17, 18] assess the whole building system. As an example, the results of thermally insulated flat roof systems are presented here.[17] These systems consist of a vapor retarder, thermal insulation, adhesives (if applicable), and the roof membrane. The ecological balance of the system components have been calculated with regard to the use of material and energy and environmental impact taking their entire life cycle into account. The investigated parameters were emissions to the environmental media water, air, and soil, as well as resource consumption. Besides the quantitative calculation of the relevant pollution and energy parameters aspects such as risk, working hygiene and consumption of resources have been included in the assessment.

It is far beyond the topic of this paper to present details of this study. As an excerpt, Figure 11 illustrates the assessment of three roof systems.

The graph does not say anything about the technical performance of the systems investigated; only the environmental impact is considered. System 1 has the lowest environmental impact (i.e., it is the most favorable system from an ecological point of view). The considerably high environmental effect of System 2 is mainly due to the amount of materials being used. Note that System 2 is a security system against penetration of water after possible damages and, therefore, makes use of more material than System 3. System 3 is closer to common practice in modified bitumen roofing than System 2. The influence of the thermal insulation is of lesser importance in this context (the cork board ranks the best,

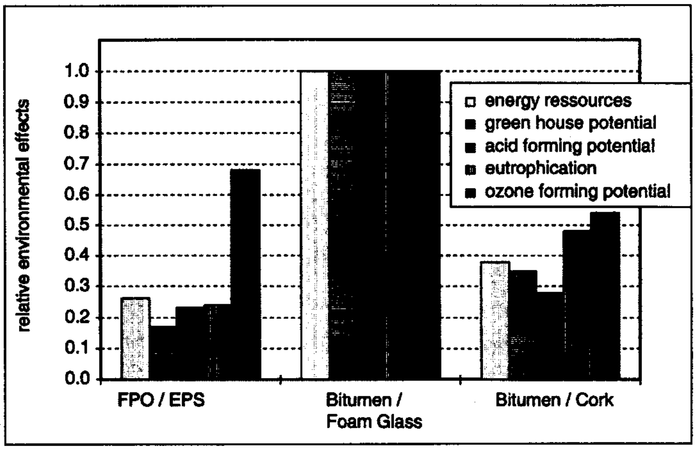

Figure 11: Environmental impacts of roof systems (see explanation in text above). System 1 Polyethylene vapor retarder, expanded polystyrene board, 0.08 inches (2.0 mm) FPO (PE) membrane; System 2 Bitumen adhesive, two layers of modified bitumen sheets, foam glass insulation; System 3 Bitumen vapor retarder, cork insulation, bitumen adhesive, modified bitumen sheet.

slightly before the polystyrene board, followed by the foam glass insulation). Polypropylene-based FPOs have not been treated in this study. Because these FPO types have an inherently higher mechanical strength than polyethylene-based FPOs, they can be used with a lower thickness. Reducing the thickness would make System 1 even more favorable, as less material would be used.

CONCLUSIONS

Flexible polyolefin (FPO) membranes have an outstanding ecological profile with regard to all environmental aspects. In particular, the ease of recycling of these materials should be noted. It is advisable not to compromise the ecological advantages by the introduction of hazardous flame retardants.

FPO membranes are expected to have extremely long lifetimes. However, proper formulations that avoid bromine compounds, that control of the thermal stability by choosing light colors and that incorporate fiberglass mats are basic requirements to achieve extraordinary long durabilities.

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