TRANSITIONS IN ROOFING TECHNOLOGY

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The term "technology" is derived from the Greek word "technologia," meaning "a systematic treatment." The English word "technology" has several connotations. For example, it can mean a practical application of a science; a method or process for handling a specific problem; or, taken in the broader context, it is the system by which a society provides its members with those things needed or desired.[1] As we use the term "roofing technology" here, it connotes the practical application of certain sciences and technologies to provide the members of the roofing community with materials, design, application and maintenance practices that are needed or desired. The motivating forces for applying new technologies in the roofing industry are often economically and performance oriented.

The purpose of this paper is to review the transitions made in the application of the various technologies within the roofing industry to improve performance and enhance the economic gain of all segments of the roofing community. This paper describes the more significant trends and developments that have occurred with the application of divergent technologies with respect to material, design, application and measurement parameters. Further, the paper speculates on the role that the application of newer technologies and the modifications in the currently used technologies will play in the future of the industry.

MEMBRANE-RELATED TECHNOLOGIES

For almost 150 years, the roof waterproofing membrane of choice in the United States consisted of multiple layers of hot-applied bitumens reinforced with felts or fabrics. In terms of technologies, these composites combined the principals of adhesive, bituminous and papermaking technologies. The initial application of these technologies occurred when the concept of layering pine tar-impregnated paper with an adhesive layer of wood pitch was put in practice to roof houses in the 19th century.[2] Although the three technologies were somewhat dormant over the next 100 years, modified applications of them resulted in monumental improvements in the art of roof membrane production.

Membrane Reinforcements

First, let us consider the reinforcing element of the built-up membrane. The more recent versions of bituminous roofing membranes hardly resemble the crude pinetar products of yesteryear. Nonetheless, the production of all reinforcing elements now used depends on felting technology that is similar to paper technology. It involves the matting of fibers together utilizing a combination of mechanical means and chemical reactions, catalyzed by moisture and heat to form the basic mat. The mat, in turn, is impregnated and sometimes coated with bituminous compounds to form the roofing felt.

Organic roofing felts, the workhorse of reinforcing fabrics in the 20th century, are now essentially obsolete as shown in NRCA's 1987 Project Pinpoint returns.[3] They comprised only 5 percent of the total roofing felt market in 1987. Historically, organic felts have undergone numerous material and property changes. Initially, the key fibrous ingredient of organic felts consisted of "rags." However, due to wartime restrictions and the influx of synthetic organic fibers after World War II, defibrated softwood chips, a product of a new technology, became the primary ingredient of the mixture of paper, rags and corrugated board which comprised organic felt.[4]

Early in the 20th century, asbestos fiber, a naturally occurring mineral fiber, offered an alternative to the organic fibers for producing roofing felts. The asbestos felts were produced using a similar felting process and the same equipment as those used for organic felts. They exhibited superior fire resistant properties, as well as excellent weathering characteristics.[5] However, Project Pinpoint returns reflect that asbestos felts became a casualty of the 1980s.[3] The demise of asbestos felt was mainly due to health concerns and liability issues, although performance deficiencies and economic matters also contributed.

During the 1950s, glass fiber technology was introduced into the roofing industry with the production of fibrous glass felts impregnated with asphaltic compounds. The use of glass fibers was an outgrowth of technologies developed during World War II where glass mats were used to reinforce enamel on pipelines.[6] When initially introduced, the producers of fibrous glass felts were faced with problems involving both application and performance. However, with technological improvements in manufacturing, design and application techniques, these problems were gradually overcome. Today, glass fibrous felts provide an excellent reinforcement for built-up membranes, as evidenced by the fact that glass commands over 90 percent of the reinforcement used in the application of built-up membrane roofing.[3]

Roofing Bitumens

The technologies associated with roofing bitumens have undergone little change as far as composition, production and application are concerned. Basically, there are two types used for built-up membrane construction: coal tar and asphalt. The coal tar and asphalt bitumens currently produced and used are essentially the same, both chemically, rheologically and physically, as those used for many years.

More than a century ago, coal tar pitch, a by-product of the "destructive distillation" of coal, was introduced as the waterproofing component for use in built-up membranes. In fact, coal tars were the predominate bitumen used until the 1920s. As with the material itself, the technologies associated with the production of coal tar pitch have undergone little change since their introduction before the turn of the century. However, a "low fuming" product was developed, patented and marketed during the 1970s.[7] In 1987, coal tar products comprised about 10 percent of the bitumens used in built-up membrane construction.[3]

As an alternative to coal tar pitch, the employment of asphalt as the waterproofing component of roof membranes occurred early in the 20th century. Asphalts currently used in built-up roofing applications are principally derived as by-products of petroleum processing. The residue remaining after the distillation of the petroleum is oxidized in a "blow still" to the desired properties.[8]

The increased consumption of petroleum products in the 1920s and 1930s resulted in a marked increase in the availability and use of asphalt for built-up roof construction. In 1987, asphalt comprised about 90 percent of bitumens used in the construction of built-up membranes.

Elastomeric and Thermoplastic Membranes

Elastomeric and thermoplastic technologies were introduced into the roofing industry in the early 1960s, but at that time had little impact.[9] However, the serious application of these technologies to membrane roofing occurred during the 1970s; this application, in turn, precipitated the so called "materials revolution" in the U.S. roofing industry. The introduction of innovative elastomeric and thermoplastic membrane materials resulted in a need for research, test methods and standards to characterize, evaluate and specify these products.[10]

The primary technologies that led to the development of polymer modified bitumens were centered in Western Europe. For example, Italy specialized in the applied technology of atactic polypropylene (APP)-modified materials.[11] France, West Germany and other European countries concentrated on the technology associated with the development of the styrene-butadiene-styrene (SBS)-modified products. These technologies, along with the polymeric modified asphalt products, were imported into the U.S. marketplace during the 1970s and now comprise 12 percent to 15 percent of the commercial roofing used.[3]

Elastomeric technology was responsible for the introduction of neoprene and butyl rubber roofing membranes in North America in the 1960s. Subsequently, the United States played the lead role in the successful application of the ethylene propylene diene terpolymers (EPDM) in the manufacture of elastomeric roofing membranes. The EPDM-based materials currently command over 34 percent of the commercial roofing membranes used in the United States. A variety of other membranes, such as chlorosulfonated polyethylene (CSPE), chlorinated polyethylene (CPE), polyisobutylenes (PIB) and the like, were introduced as alternates to conventional bituminous roofing and have had significant impacts on roof membrane applications.

Thermoplastic technology was first applied to roof membrane development in the 1960s and 1970s, primarily in Switzerland and West Germany. This technology and roof membrane products based on it were imported into the United States during the 1970s, mostly in the form of polyvinylchloride (PVC) membranes.

The application of the elastomeric and thermoplastic technologies has brought about the introduction of a multitude of products previously unheard of in the roofing industry. With some notable exceptions, the polymer-modified bituminous, elastomeric and thermoplastic membrane materials have had a history of good performance. They have steadily increased in use. The 1987 Project Pinpoint returns show that products based on these technologies command between 55 percent and 60 percent of the total U.S. commercial roof membrane market.[3]

Some Projections

At first blush, it may seem that the roofing industry has reached the saturation point for the application of new technologies for roofing membranes. However, we project that modifications of the current technologies will continue to occur to improve performance and enhance economic gain. New and different polymer modifiers will appear to enhance the properties of coal tar and asphaltic products, especially in the area of the polymer-modified bituminous membrane products. The industry will experience increased use of glass and polymeric reinforcements for the modified bitumens. The use of polyester felts for hot-applied and liquid-applied membranes systems will continue to increase. Cold-appliedadhesives for the application of polymer-modified bituminous materials show much promise. As an aside, we foresee that the current trend toward metal as an alternative to the various organic membranes for use in low-slope roofing will show a marked increase, thus adding metal technology to the inventory of roof membrane technologies.

In summary, the application of roof membrane-related technologies has experienced a phenomenal growth in the developed countries during the last three decades. The more traditional membrane technologies have given considerable ground to plastic, polymer, glass and metal technologies. The change has been good for the roofing industry and the consumers it serves. It is hoped, the trend toward applying new technologies and modifying current technologies to roof membrane design, development, application and maintenance will continue to improve performance and enhance the growing reputation of the roofing industry.

INSULATION-RELATED TECHNOLOGIES

The major utilization of thermal insulations as roof system components occurred over the past 50 years. Previously, roof membranes were placed directly over structural roof decks. In early times when insulations came into use over the structural deck but beneath the membranes, they consisted of board stock composed of either cork or wood and mineral fibrous materials. Other, somewhat pragmatic, procedures were sometimes used to increase the thermal resistance of roofing systems. As an example, ponded water on the roof served as the thermal barrier component. Due to performance problems and weight concerns, the ponded roof became essentially extinct.

After World War II, the United States experienced an increased use of metal decks for the structural roof platform. These metal decks require rigid insulation to span the ribs of the deck. This, along with the increased use of air conditioning and rising energy costs during the energy crisis of 1973, resulted in the common practice of placing thermal insulations within the roofing system. Now approximately 85 percent of all commercial/industrial roofs are insulated.[3]

Corkboard, like the ponded roof, is extinct. However, mineral and wood fibrous board products continue to be used in substantial amounts, each about 10 percent of the total market, as the insulation of choice.

Glass Technology

The application of glass technology to roofing was not restricted to fibrous glass membrane reinforcements. It played a major role in the development of fibrous glass as an efficient thermal insulation for roofing applications.[12] It is produced in higher density than commonly used in fibrous glass blankets. When produced with an appropriate facer to control bitumen flow, it possesses suitable mechanical properties to serve as one of the essential components of the roofing system. In 1987, fibrous glass insulations accounted for almost 12 percent of insulations used in roofing applications.[3]

Another glass-based product, referred to as cellular or foam glass, has been available for many years as roof insulation. It possesses many desirable performance characteristics, such as excellent structural properties and water resistance characteristics.[13] However, due to its relatively high cost and limitations on its thermal efficiency, its use has been limited to special projects.

Polymeric Technology

The ever increasing costs of energy over the past two decades precipitated a need for more thermally efficient products. This provided the opening for plastic foams to make their mark on the U.S. roofing industry. The chemical names of polyurethane, polyisocyanurate, phenolic and polystyrene became common terms in the roofing area.[14,15] Technically speaking, the foams are produced by the reaction of chemicals in the presence of additives, catalyst and sometimes heat to create tiny gas filled cells. The high insulating quality of cellular foam products is derived from high concentrations of gases trapped in the cells. In the case of the urethane, phenolic and isocyanurate products, the cells are filled with fluorocarbon vapor, which possesses a very low heat conductance value. With the advent of a recent international agreement limiting the production of certain chlorofluorocarbon gases because of their detrimental effects on the atmosphere, considerable concern has been raised in this segment of the roofing industry. As with refrigerants, a quest for suitable alternatives is underway.[16]

Often what the cellular plastic foams offered in thermal efficiency, they lacked in mechanical performance characteristics. Again technology and innovation was brought to bear in providing facers, reinforcements and the like to overcome the inherent limitations. Further, techniques were developed for layering plastic foams into composites with mineral, glass and wood fibrous materials to blend thermal and mechanical characteristics to improve performance.[17]

A major transition of cellular plastic technology applied to roofing occurred in the 1960s. An innovative use of spray-in-place polyurethane foam as a roofing system attained some prominence in the United States. Basically, the roofing system consists of a sprayed-in-place layer or layers of urethane foam covered with a protective membrane or coating.[18]

Other Insulation-Related Technologies

Another advancement in insulation technology was provided by the introduction of tapered foam glass products many years ago, perhaps as a compensation for poorly designed roof decks.[13] Several other generic insulation products have followed this lead and now serve not only as thermal insulations but also provide positive slope to drain when installed into the roofing system.

The advent in the 1960s of the protected membrane roof system, where the thermal insulation is placed above the roof membrane, depended largely on the water-resistant properties of the insulation component. Again technology served as the vehicle to develop manufacturing techniques to produce extruded polystyrene that had the required freeze/thaw and moisture resistance properties in protected membrane applications.[19]

DESIGN-RELATED TECHNOLOGIES

Design practices reflect the application of new technologies in roofing. For example, the elementary roofing system of a structural deck supporting a water-resistent membrane, accompanied by appropriate flashing details, was the common design practice in the United States early in the century. With increased emphasis on heating and cooling of buildings, the need to add a third insulating component to the roof became apparent. Now the designer was faced with the situation of how to control the moisture vapor flow from a building's interior into the core of the roof system, hence the need for a vapor flow retarder. The roof system now became a rather complex composite of four or more basic components due to changing technologies. The evolution of design practices is evident from multifarious design parameters as reflected in the current literature.[20]

The changing design practices precipitated problems that demanded solutions, which in turn created problems that demanded further solutions and so on. An example is the insulation attachment issue. Initially, good design practice dictated that the insulation component be securely attached to the substrate. Using the excellent adhesive properties of hot-applied bitumens, this was satisfactorily accomplished. However, due to fire safety considerations, especially with metal decks, this practice gave way to use of thin plastic adhesives and films as the vapor retarder and adhesive used to secure the insulation. The application of plastic technology to roofing added further complications. The plastic adhesives often proved to be inadequate to securely attach the vapor retarders and the insulations. In turn, the moving insulation precipitated membrane shrinkage, uplift and splitting failures and other related complications. To counteract this problem, the advent of mechanical attachment of insulation to metal decks became the accepted practice in the late 1970s. As a result the industry has experienced the introduction of various kinds of plastic and metal fasteners and fastening systems as the overall solution. The positive results of the impact of this design feature solution on the roofing community are already apparent. Nonetheless, some concerns about corrosion, holding power, backing out and other potential problems with fasteners in all membrane roofing systems have also been raised.

The introduction and growing use of elastomeric and thermoplastic membrane materials as well as the many innovative insulation products has necessitated many design and application changes. This is primarily due to the radical property differences of the newer materials when compared to the more conventional bituminous materials. For example, loose-laid, partially attached and fully adhered are now design options available to practitioners in designing and applying certain membranes and insulations, depending on the materials selected for the roofing system. The newer membranes are often specified in single layer configurations, which calls for special precautions in lapping practices. Heavy aggregate or concrete paver surfaces dictate special design considerations especially in areas of safety. Construction details for flashing vertical surfaces, penetrations and the like need to be compatible with material properties of the various components of the roofing system. These are but a few of the issues that face today's designer and applicator who utilize roofing systems based primarily on elastomeric and thermoplastic technologies.

The impact of technology on design and application practices has been significant. The introduction of innovative products through technology has given the designer more options for providing good performing roof systems for all types of buildings. The negative aspects of applied technologies have also been apparent. This frequently results not from the technology itself, but from the deficiencies of the manufacturer, designer and applicator, who fail to learn the material, design and application requirements necessary for an adequately performing roofing system. All in all, the positive impact of the new technologies has far outweighed the negative aspects, and the roofing community has kept pace with the state-of-the-art of modern construction and will continue to do so in the future.

MEASUREMENT-RELATED TECHNOLOGIES

Measurement and characterization technology for low-slope commercial and industrial roof systems has advanced more in the past two decades than it has over its previous history in the United States. Early this century, the initial requisites for the basic elements of multiply bituminous roof membranes were promulgated through standards developed by ASTM Committee D-08 on Roofing and Waterproofing, which was organized in 1905. Companion ASTM documents defined rather simple and uniform test methods to measure desirable properties. Over the years, ASTM committees and others continued to add to the inventory of techniques for measuring the properties of all the components of low-slope roofing systems.[21] These documents included decking materials, vapor retarders, insulations, membranes and protective surfacings.

ASTM now has literally hundreds of standards describing test procedures for measuring properties and, sometimes, performance characteristics of roofing materials and systems. From this information, the conclusion may be drawn, and rightly so, that roof measurement technology has come a long way in the 90-year history of ASTM. The question continuously arises: Has the roofing industry gone far enough? The answer is no! The majority of ASTM test methods are empirical in nature and define, in prescriptive terms, material properties of the basic constituents of roof system components that are unrelated to performance under service conditions. The need for better standard test methods is clear. It is recognized that measurement methods need to be developed that are directly related to on-the-roof behavior. If such standard measurement techniques were available, the next step would be the development of performance criteria to complement the prescriptive requirements now available for most roofing materials and components.[22]

In the late 1960s international efforts were under way to promote the use of performance requirements for building construction. As defined, performance standards would include a set of performance requirements that projects end-use behavior rather than prescribes the nature of materials, how they are manufactured and how they are applied. The movement to adopt such standards provided the impetus for the development of performance measurement techniques for and by the roofing industry.

Fire safety test procedures for roof systems, promulgated by ASTM, Underwriters Laboratories and Factory Mutual, were the forerunners of true performance testing for roofing. Heat and moisture flow test methods also appeared along with the development of equipment and instrumentation to measure these parameters in a roofing system. Subsequently, wind uplift methods, for both laboratory and in situ testing for performance under wind loading, were described in consensus standards.

Research conducted in the 1960s resulted in developments of procedures for measuring such engineering properties of bituminous membrane as load, elongation, thermal expansion and thermal shock. This was a first in over 100 years of use of these products. More importantly, the relation between laboratory measurement and in-service behavior was established. These events were followed by a breakthrough in roof performance testing that occurred in the early 1970s. The research, which appeared in the form of a National Bureau of Standards publication, described test methods for measuring nine performance attributes for bituminous built-up membranes along with recommended quantitative criteria for each of the measured attributes.[23]

Since the appearance of the above and subsequent documents, improved and often innovative test methods for roofing have been developed largely due to the expertise of competent engineers and scientists supplemented by modern test apparatus, applied electronics and computer utilization for test control and data analysis. These developments have provided the roofing industry a potential for making giant gains in measuring performance parameters related to materials, composites and systems. On the negative side, it seems clear that the industry has failed to take full advantage of these advances in measurement technology and to apply them to more and better performance standards. Fragmented research efforts, lack of funds and the absence of a national research plan have certainly had negative impacts. The multifarious products and systems that have inundated the U.S. roofing marketplace without the benefit of research and in-service experience have provided serious constraints in the advancement of the state-of-the-art in measurement technology.

On the positive side, there seems to be a bright future for measurement technology in roofing. Techniques that are new to the roofing community are being discussed, explored and applied. For example, the application of simulation modelling using mathematical approaches is a promising reality.[24] The feasibility of using expert systems, a computer-based diagnostic tool, for problem solving is being studied. As a result of the recommendation of an international committee, research is now under way in the United States and abroad to utilize thermal analysis test methods for the evaluation of in-service performance of all types of roof membrane materials.[25]

Transitions in roof measurement technology have indeed advanced a long way as the industry gains knowledge about the attributes required for acceptable performance of products and systems. Nonetheless, the roofing community still has a long way to go.

SUMMARY AND COMMENT

In the last century, the art of roofing in the United States was primitive yet effective. Early innovators, sensing the prospect for improved roof performance, applied some elementary scientific concepts to the art, and roofing technology was born. Initially, the technology remained rather stagnant due to the basic design of early roofing systems and the rather simplistic needs of the building user. In the early years of the 20th century, the pace began to accelerate. The demands for more efficient and comfortable buildings precipitated increased demands for better materials, better standards, better application and consequently better performing roofing.

Advancements in roofing technology began to accelerate at an ever increasing rate as the century progressed. Major milestones that impacted technology change were, among others, changing national economies, improved industrial practices, the advent of the automobile, world wars, energy crises, material shortages, scientific advances, ascetic considerations and the like. Entrepreneurs, motivated by the enormity of the U.S. roofing market, introduced new materials, designs and application practices, which produced major transitions in roofing technology. Unfortunately, many of the new technologies resulted in new problems demanding solutions. New technologies were applied to provide these solutions and so on. Research and standards development for roofing materials and systems also resulted in the application of measurement technologies to add to the growing technology of roofing.

Transitions in roofing technology have been many and significant. There has been a greater advancement in roofing technology over the past two decades than ever before in the history of roofing in the United States. These advances have resulted in better products, better design and application practices, more efficient and more comfortable buildings and much improved cost-effective roofing performance. Roofing technology has come a long way but the industry still has a long way to go.

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