Design and application principles

Kalinger, P.

Design and application principles

Kalinger, P.

NRCC-40627-2

Building Better Roofs: IRC Technical Seminar, 11 Cities Across Canada, September 1996-February 1997, pp. 1-15

Design and Application Principles

Peter Kalinger
Canadian Roofing Contractors' Association

The roofing industry has witnessed tremendous changes in the way we build roofs over the last three decades. Never before have contractors and designers had such a large variety of materials, systems and assemblies to choose from when designing a roofing project. Brought about by advances in material sciences, computer-assisted engineering and design, and years of intensive research in materials and systems behaviour we now have available to us a plethora of products and roofing options.

We are told by some manufacturers that, according to their testing, we can select products that can withstand the harshest extremes of climate and exposure. We have products that, according to their claims, will perform in temperatures ranging from well below freezing to near the boiling point of water. They will resist rot, fungal and chemical attack. They will remain flexible for years, are almost totally UV resistant, are unaffected by water and are both abrasion and impact resistant. Contractors and others may claim that if properly installed and with a minimum amount of care and maintenance, these products should remain in service and trouble free for decades. Some even offer longterm warranties to back up these claims.

Why then, do we continue to be plagued with roofs that leak just a few years after their initial installation? Why are millions of dollars spent annually in repairing, or replacing roofs that were expected to give uninterrupted service for decades. Why is so much construction litigation and claims still related to roofing?

Our immediate explanation as to the underlying cause might be that our expectations were just overly optimistic, or that in the worst case, we were simply misled by overzealous marketing departments.

Along with the huge increase in the diversity of roofing products and systems has come an increase in the complexity of roof construction. Different materials require different application techniques and detailing. Building scientists have demonstrated that the roof is not a static component of a building but behaves in a dynamic fashion, subject to a wide array of loads, forces and stress during its service life. We are now aware that the relation of the roof to the other parts of the building envelope and how they are connected is critical to the overall performance of the roof and the building itself. However, when we look more closely, we soon discover that the cause of these chronic problems is generally not based in the "new materials, or a failure to understand how roofs behave" but the lack of attention to basic principles that should guide both our design and application. Although these principles are fundamental and have changed relatively little since the inception of roofing, from time to time we choose to ignore them at our peril. Perhaps we have been lulled by lengthy warranties, unrealistic expectations by manufacturers' claims, or we have simply forgotten them. Nevertheless, adherence to them is the only way we can build roofs that will last.

The performance of any roof is ultimately dependent on three key elements:

- proper design
- proper application
- regular maintenance

Each of these elements must be present if the roof is to provide satisfactory performance over its full expected service life. Each requires a sound understanding about how roof assemblies and their components behave, what conditions will affect their performance, and what measures must be taken to ensure that the harmful effects of exposure and use will be minimized.

We are all accustomed to speaking of roofs in terms of life spans that approximate twenty years. We are also aware of numerous examples of roofs that have ceased to perform, or remain watertight well before that time. This is often referred to as "premature failure". Under close scrutiny, it is usually revealed that the cause of these "failures" is rooted in an inappropriate initial design, improper installation, misunderstanding of the roofs particular requirements or a disregard for the need to provide routine and regular maintenance.

A roof can be considered as one of the crucial components of the building. Obviously, it serves to act as a barrier that shelters the occupants and contents from the exterior natural elements such as rain, snow and sun. It must also serve to provide structural support; protection from fire from both without or within; from the infiltration or exfiltration of noise; control of the flow of heat; and the flow of water vapour. In addition, roofs are increasingly an important architectural feature of the overall design, and must meet aesthetic requirements.

To meet these demands, roofs must be constructed so that they will provide satisfactory performance throughout their design service lives. Durability, reliability and maintainability are fundamental concepts in the design and construction of performing roofing systems. These, in turn, are dependent on their initial design and construction and an appropriate level of post construction maintenance.

DESIGN

All too often the design of a roofing assembly is based on historical or anecdotal experience about what systems or products have worked in the past as opposed to the particular requirements of a specific project. No doubt selecting materials and systems that have a proven track record is sound practice, but to ignore all other alternatives for the sake of expediency may deprive the owner of the optimal and most cost-effective roofing system. At worst, it can lead to catastrophic problems when an ill-suited assembly is chosen solely based on its record in past projects.

The designer must, at conception of the roofing project, embark on a rational and vigorous decision-making process to ensure that the appropriate system is chosen. To achieve this effectively, the designer must obtain a thorough knowledge and understanding of the requirements of the roof, its conditions of exposure and usage, as well as the physical properties and the behavioral characteristics of the materials being proposed.

A good rule to follow is one expressed by Marshall McLuhan who said "form follows function". Only once the functions of a roof, together with its conditions of exposure, are accurately defined can the options be narrowed and the appropriate system selected. By working through the following checklist, a designer can develop specifications that will help ensure that the roof provides the expected performance throughout its anticipated service life.

Geographical Location

The geographical location of the project site will determine the climatic conditions to which the roof will be subjected. This information is of paramount importance in the selection of products and systems. Average rainfalls, snow accumulation, wind speeds and daily average temperatures will dictate the assembly requirements. Dewpoints, vapour transmission rates, roof top temperatures and anticipated live loads resulting from the accumulation of snow and rain are all dependent on the climatic conditions at the project site. The climatic conditions, in turn, will prescribe the suitable materials and the configuration in which they can be employed. By example, a membrane with low strain energy is probably a poor candidate to use in an area in which large thermal shocks due to rapid changes in temperature are common. Organic materials, such as cellulosic roofing felts, may not be suitable in regions where a hot humid environment is the norm.

Climatic conditions will also determine how the system is to be attached to its structural support. Factory Mutual, for example, bases the approval of roofing systems on wind zones for particular geographical regions. General wind load guidelines for structural or load resisting/bearing elements and determining snow loads for a particular region can be found in Part 4 of the National Building Code of Canada.

Design Load Limits

The capacity of the structure, particularly the roof deck itself to sustain the loads to which it will be subject, will limit the system options available to the designer. This may preclude the use of ballasted systems, typically weighing 55 kg/m^2, or protected roof membrane assemblies. The designer must also be aware that the choice of the roofing system may influence the loads to which the structure will be subjected (i.e., snow accumulation). The necessary calculations are relatively simple in new construction but may be more difficult in the case of re-roofing or re-covering of existing roofs, a growing trend.

Split System

The need for a continuous vapour retarder in conventional compact roof assemblies, to prevent moisture accumulation due to vapour diffusion under certain climatic conditions is reasonably well accepted. This can, however, present a difficulty for the designer who specifies the mechanical attachment of the insulation and membrane. The risk of compromising the vapour retarder is quite high when systems must be mechanically attached. According to Wayne Tobiasson, of the U.S. Army Cold Regions Research and Engineering Laboratory, mechanical fastening in itself may not significantly alter the rate of vapour diffusion if the fasteners penetrate the top flange of the deck and have sufficient clamping force.[1] However, as is well known, perfection is difficult, if not impossible, to achieve during construction. Damage during construction, improperly placed or occasional defective fasteners, fastener back out, plastic creep of insulations and thermal bridging, may all compromise the vapour retarder's integrity and lead to accumulation of moisture within the roof. The most effective means of resolving this problem is to follow the recommendations of CRCA (Canadian Roofing Contractors Association) and FME (Factory Mutual Engineering Corporation) and construct a "split system". In this configuration, a thin layer of roof insulation, thick enough to effectively span the flutes, is fastened to the deck. Over this base layer, a suitable vapour retarder can be applied. In most instances, this consists of two layers of asphalt felt mopped into hot bitumen. Finally, the balance of the insulation and membrane covering is applied.

There are numerous advantages to this type of application.

1. The air/vapour retarder is not compromised by the penetration of fasteners.
2. Potential for damage from traffic during construction is greatly reduced.
3. Thermal bridging at fasteners is virtually eliminated.
4. Shorter fastener lengths are required. This is particularly appropriate on projects where thick amounts of insulation, flat or tapered, are required.
5. With proper bitumen type, the wind uplift requirements of FM, ULC and the National Building Code are satisfied.
6. If the base layer meets the requirements of a thermal barrier in accordance with ULC-CAN4-S124-M, many alternative types of insulations and membranes may be used.
7. Allows large areas of the roof to be rendered watertight in a given unit of time, thereby enhancing construction schedules.

Roof Decks

The type of deck will determine the way in which the roof system is secured. Increasingly, mechanical attachment is the preferred method of securing roof insulation to steel decks. In fact, FM, as early as 1983 has accepted only this method of attachment. Some insulation manufacturers, particularly those manufacturing foam insulation, will not accept the installation of their products with cold solvent adhesives. Hot asphalt is still the preferred method of securing roofing to concrete decks while the attachment to wood decks continues to consist of either mechanical fasteners or hot asphalt.

In any event, the designer must, when preparing his specifications, consider how the roof system is to be secured and held in place. Bob Turenne, of NRC/IRC, in the late 1970's demonstrated that uniform attachment was a critical factor in the prevention of shrinkage and splitting in BUR roofs.[2] Correct and sufficient attachment of components is equally important in the construction of lightweight single-ply systems.

Even loosely laid and ballasted single-ply systems can fail should their attachment not be thoroughly considered. In this instance the gravel cover normally provides the wind uplift resistance of the assembly. However, sufficient attachment of the membrane at the perimeters and openings is critical to prevent tenting and rupturing of the perimeter membrane flashings which will compromise the integrity of the system.[3]

Roof Slope

It will come as no surprise that adequately draining a roof is necessary for its longterm performance. In 1978, Donald Smith, Roof Consultant, delivered a report to Canada Mortgage and Housing Corporation titled "Performance of Roofs Relative to Design Slope". [4] In this survey of 67 roofs, with slopes ranging from 0 to 1.6%, more than 39 roofs (58%) were experiencing some sort of leakage. Yet, the number of roofs that are still being constructed near or dead level is alarming. This has been a result of the misguided belief that adding slopes will substantially increase the cost of construction or that some roofing materials are unaffected by water. While it may add marginally to the cost of the initial construction, these costs will be more than off set by avoiding the higher repair and replacement costs associated with dead level flat roofs.

With respect to the claims by some manufacturers that their products are not affected by standing water; these claims should be treated with scepticism. Evidence has shown that some of the adhesives used in elastomeric sheet lap seams suffer loss of tensile strength when submerged. Some single ply materials, although only slightly water absorptive may swell or wrinkle with prolonged exposure to water. Other materials are subject to microbial attack in areas of ponded water. Perhaps most importantly the smallest defect in the membrane, particularly at a lap, can lead to catastrophic leakage in ponded areas. A small wrinkle or fishmouth in the membrane has been known to result in sufficient water infiltration that the replacement of the entire roof was required.

Even on existing roofs, where costs would prohibit structural modifications, drainage can be greatly enhanced by the addition of new drains in ponded areas or the installation of tapered insulation systems and counter slopes. Care must be exercised, however, to ensure that additional insulation at edges and parapets do not reduce their flashing heights to the extent that they can be overwhelmed.

Building Occupancy

The environment of the building interior and its occupancy will establish many of the requirements of the roofing system. Wet process manufacturing, swimming pools, hockey arenas all provide examples of constructions where the roof's vapour/air retarder will be crucial in its overall performance. The need for sound attenuation may preclude the use of certain materials which have a low sound absorbency. Roofs carrying a lot of equipment that must be regularly serviced may need membranes that are non-slip, tough and have a high degree of impact resistance.

The waste and effluents exhausted onto a roof can have catastrophic effects on its performance. Care should be exercised in determining the nature of the exhausted substance and the potential effect they may have on the roofing membrane.

Insulation Requirements

The total thermal resistance of the roof assembly will be dictated by the building occupancy, its interior environment, size, height and shape. In some instances, a minimum may be statued by Code. In other instances, the payback period and cost/benefit analysis will determine the optimal thermal value for a given project. The thermal component of any commercial/industrial roof is probably its most important function next to being a barrier to rain and snow.

A myth regarding the effects of increased insulation and thermal resistance on the performance of most roofing membranes that has permeated the industry needs to be dispelled. The myth is that thicker insulation will accelerate the deterioration or aging of the membrane due to the increased temperature effects. The theory goes as follows: Because of the higher thermal resistance of thicker or more efficient insulations, the membrane will be subjected to a broader range of temperatures (i.e., summer would produce much higher temperatures and winter much colder) resulting in more rapid chemical degradation and large thermal shocks. The facts are that research by Drs. Rossiter and Mathey of NBS, showed that membrane colour has more effect on the surface temperatures than does a change in the insulation thickness.[5] Moreover, work by David Richards and Edward Mirra demonstrated that during cold weather, a heavily insulated membrane may have even less temperature change than a lightly insulated membrane.[6]

This does not imply that thermally efficient roofs are problem free, but it does show that they are not directly caused by any significant change in the surface temperature to which the membrane is subjected. Splitting, deformation, slippage and a host of other anomalous conditions have been reported on highly insulated roofs. It appears, however, that the contributing factors to these problems are related to the difficulties in restraining the membrane undergoing temperature induced loads.

Size and Shape of Roof Structure

The effects of temperature, moisture, wind, seismic loads and numerous other conditions can cause significant movement and dimensional changes in structures and their components. Anticipated deformations and stresses are typically accommodated by the installation of expansion joints. Although building size may be the most important determinant for the placement and number of expansion joints, the building shape may also be a factor. Roof splitting has been known to occur at changes in span direction, at the junction of different deck types, at the junction of wings of a building and over end joints of simply supported beams and deck units. The design should incorporate allowance for movement at these locations.

It has been suggested that even if expansion joints are not required, "membrane control joints" or breaks in the membrane covered by a flexible flashing, be used to control tensile forces. Their use has been based, for the most part, on erroneous assumptions, particularly about the properties of BUR membranes. These assumptions include the belief that BUR membranes behave elastically, that decreasing the surface area by providing membrane control joints will reduce membrane shrinkage and that by transmitting stress to the membrane control joints, membrane stress will be relieved. It has been shown that BUR membrane behave visco-elastically, behaving like a viscous fluid at high temperatures and almost elastically at low temperatures.[7] As a result, not all the thermally induced stresses are reversible and the tensile forces are not necessarily proportional to size. Since the shrinkage of the membrane may continue over time, the membrane will migrate inwards to the centre. As a result, the control joints will continue to open up until such time that ruptures and leakage results. Membrane control joints build in an area of weakness into the roof and should be avoided.

Roof area dividers however, can serve several useful purposes. By breaking up irregular shaped roofs into smaller units, future servicing, repair and re-roofing become more manageable. They can also serve to provide effective water cut-offs from one roof section to another. They can reduce the stresses associated with re-entrant corners in irregularly shaped roofs or those with large projections. In loose laid systems, since membrane shrinkage is proportional to size, smaller roof sections delineated by roof area dividers can lower the stress placed on fasteners and the perimeter attachment.

Design Details

An overwhelming proportion of defects and leakage in roofs occurs at the perimeter, intersections of walls and parapets and at penetrations. Although it is relatively easy to design and construct an impermeable roof cover in the horizontal field, changes in plane and terminations pose particular difficulties. At these locations, flashings are subjected to some of the most demanding conditions on a roof. They are typically located at points where two planes of different materials, each having a different thermal characteristic, intersect. For example, the intersection of a metal and cement block wall or a concrete deck and metal curb. In addition, they are exposed to the most severe weathering and the actions of sunlight, wind-driven rain and snow, capillary forces, and gravity. Careful attention to details is essential for successful longterm performance, regardless of the type of roof construction.

When designing specific details for a particular roofing project, the designer should consider the material requirements and recommendations obtained from the manufacturer. Wood nailers and blocking should be provided at roof edges and other points of termination. They serve to provide protection for the edge of the insulation and a base for anchorage of the membrane and membrane flashings. They must be securely attached to the deck to be effective. The designer should clearly stipulate the manner in which nailers and blocking are to be incorporated into the details as well as the method of attachment.

If the building is required to comply with FM or ULC, the designer should consult FMRC or ULC publications. FMRC's Loss Prevention Data Sheets 1-49 deals specifically with fastening and attachment requirements for perimeter flashings that pertain to both conventional and non-conventional roofing systems.

Many manufacturers of roofing membranes now offer prefabricated flashing components. Specifics for these proprietary components and flashing detail designs vary widely. The individual manufacturer's requirements should be followed in these cases.

Since metals have different thermal expansion and contraction characteristics than most roof membrane materials, the metal flashings should be isolated from the membrane wherever possible. Embedding the metal flashings into the roof membrane can result in differential movement that can fatigue the membrane and eventually cause splits, tears or cracks.

With today's construction practices, the roof is often used as the location for heating, and air handling equipment. Performance problems at these locations can often be attributed to faulty design of the mechanical unit housing and equipment and the lack of clear responsibility for its installation and weatherproofing among the involved trades. Often, improper weatherproofing of the exterior shell has resulted in direct water ingression through the units. Sometimes the failure to provide adequate means of attachment for the membrane or mechanisms for overlap have resulted in substantial leakage. Furthermore, as this equipment normally requires routine servicing, walkways or other means of protecting the membrane around the units must be provided.

The effect of the curb location should also be considered when designing the roof. Curbs placed in valleys, low areas or close to drains can restrict the drainage of surface water from the roof. Saddles and crickets to provide counterslopes should be installed at curbs that may impede drainage. Curbs should never be placed over expansion joints or so close to protrusions, walls and parapets that there is insufficient clearance to allow for maintenance or servicing of the roof.

In many instances, when a pipe to conduit penetrates the roof, designers have resorted to the use of "gum boxes" or "pitchpans" filled with roofing mastic. Although perhaps expedient and inexpensive, it is strongly recommended that these be avoided. Pitchpans have been shown to be a constant source of problems. They are not continuously watertight, require frequent inspection and continuous refilling and maintenance. Accessory products designed specifically for sealing cables, pipes and conduits into roofs should be used instead.

Design Objectives for Flashings

Achieving perfection in constructing roofing details is difficult to achieve. Even when the roofing details are perfectly constructed, exposure and inevitable building and membrane movement is likely to compromise their integrity. Since flashings are so vulnerable, their proper initial design is paramount. The following are some design guidelines that should be adhered to wherever possible.

1. Separate the membrane from the metal flashings. Where they can not be separated, allowances for movement in the design must be made.
2. All flashings must be kept well above the highest waterline in the roof.
3. All movement and expansion joints should be kept at the high points of the roof to ensure that water drains away from the flashings.
4. All metal cover flashings should be sloped so that water drains off of them.
5. All metal flashings should have watertight joints that avoid buckling or breaking from thermally induced movement. Face nailing and exposed fastening should be avoided for this reason.
6. Base flashings should never be solidly adhered to adjacent building elements between which movement is expected.
7. The membrane flashing should not be expected to provide perimeter anchorage for the membrane. This should be provided by fastening to the deck, wall, or to blocking which is securely fixed and provided for that purpose.

APPLICATION

The second element required for ensuring that a roof is constructed in a manner that will yield its full expected service life is correct installation. The best engineered materials and designed systems will soon fail if they are not properly applied or constructed.

The roofing contractor is, unfortunately, faced with the most difficult aspect of roofing - its actual physical construction. Working to tight construction schedules and often battling the elements under less than ideal conditions, it is sometimes a surprise that anything works at all. When it does, the roofing contractor is usually the last to get the credit.

Again, there are fundamental application principles that must be followed to achieve a problem free roof. Although there are new types of products being used and some of them require radically different application techniques, the old principles still apply. Irrespective of the material or system, the designer and the roofing contractor require a sound knowledge of the materials being installed and must understand their characteristics and limitations. There is very little in terms of the margin of safety with respect to roofing applications. A small precaution not taken or insufficient preparation can often lead to total disaster.

Pre-Job Conference (PRC)

Even if the designer has prepared a sound and complete set of plans and specifications, a roofing project can go awry during the construction process. This is hardly ever due to a deliberate attempt by the contractor to do poor work. It is most often the result of a failure to anticipate potential problems or effecting inappropriate solutions and ad hoc modifications when on-site changes are required. This can be avoided, if not entirely prevented, by the simple implementation of a pre-roofing conference prior to the installation of the roof.

The pre-roofing conference (PRC) is essential to review the roofing procedures, plans and specifications and to coordinate the roofing operations with other members of the construction team. The meeting should include representatives of the owner, designer, general contractor, roofing contractor, any trade contractors associated with the roof construction, the roofing consultant and the material suppliers. It should be held prior to the startup of the roofing but only once the deck has been completed and is ready for roofing so that it can be inspected for its readiness.

Plans and specifications must be reviewed, potential problems identified so that any necessary modifications can be discussed. Access to the site, production schedules, material ordering, handling and protection should be thoroughly reviewed. At this stage, contingencies can be put in place to resolve any difficulties arising from weather conditions, work of other trades or site conditions.

It is necessary to arrange for dry storage of the roofing materials and their protection from moisture, sun, rain and snow. This is a divided responsibility between the general and roofing contractors. Materials must be stored and protected so as to minimize their handling and to protect them from the elements.

Preparation of Decks

All too often the contractor is called upon to commence work before the deck has been completely prepared. Cants, wood blocking, reglets and parapets must be in place as their securement is critical to the success of the details. All projections, such as drains, pipes and curbs must be in place so that proper terminations and details can be properly executed. Particular attention has to be paid to locations where the roof ties to the other components of the building exterior, such as the wall air/vapour retarder, expansion joints or cladding elements. It is the responsibility of both the general and roofing contractors to ensure that decks are clean and dry.

In winter, it is essential that all ice and snow be removed from the flutes of steel decks to avoid future moisture problems.

Certain job conditions may require the use of a temporary covering to render the building watertight until the permanent roof can be put in place. Such temporary roofing should never form part of the finished roof. Invariably, temporary roofs are subject to deterioration and damage and if left in place, these defects will be built into the permanent roof. The same principle applies to temporary seals used to separate roof areas and provide cut-offs during construction. Failure to completely remove these cut-offs as the work progresses will build susceptible areas of weakness into the roof system.

At the edges of the roof and at intersections with higher walls, cut-offs consisting of the vapour retarder wrapped over the edges and back over the top of the insulation can be effective in preventing moisture infiltration into the roof through the exterior walls, from inside the building and from leaks at the roof wall junction. In loose laid ballasted systems, this can be achieved by securing the air vapour retarder to the vertical wall above the insulation. The membrane is then carried down over the air vapour retarder and sealed with a strip of butyl tape or a compatible sealant.

Roof Assembly

Each component of the roofing system must be applied in strict accordance with the manufacturer's printed instructions and the project specifications. If there is any conflict between them, it should be resolved at the PRC prior to the work starting. It is essential that the roofing contractor understand the functions of the roof, the properties of the materials being applied and the environmental conditions that effect them. Each particular product requires a different form of preparation and application procedure. The failure to exercise care in the preparation or conditioning of materials prior to their installation may have disastrous consequences. The following are some of the requirements of different roof materials that must be met in order to avoid future performance problems.

Bituminous Roofing

Asphalt is one of the most important elements in conventional built-up roofing systems. Since the late 1970's, considerable research on bitumen used for BUR has led to the adoption of EVT (Equiviscous Temperature) as the measurement for determining the correct temperature for its application. Simply defined, EVT is the temperature at which bitumen attains the proper viscosity for built-up membrane application. The EVT application range is approximately 15°C above or below the EVT of the given asphalt type. For mop application, the viscosity of the asphalt should be 125 centistokes (CST) and for mechanical applications it should be 75 centistokes (CST). If the bitumen is above the recommended upper EVT limit the asphalt will be too liquid resulting in too thin a layer of interply mopping. Below the recommended limit, it will be too viscous resulting in too thick a layer, resulting in possible slippage of the felts, poor adhesion and voids. Winter weather poses particular hazards. Asphalt chills rapidly and the potential of too viscous an asphalt is high. The contractor must be aware of these hazards and take the necessary precautions. Insulating transmission pipes, asphalt carriers and luggers and ensuring that the asphalt source is close to the location of its application will help to mitigate these hazards. Of course, care must be taken to ensure that the asphalt is never heated close to its flashpoint or above its final blowing temperature for any extended period of time.

Felts

Although organic felts are still the most widely used in Canada, fibreglass roofing felts are capturing an increasingly large part of the BUR roofing market. Whichever felts are used, the rolls must be stored in a warm and dry area prior to their use. Asphalt felts, can deteriorate rapidly when exposed to moisture. Dr. Laaly has shown that they can lose as much as 20% of their tensile strength in just one cycle of wetting and drying.[8] Although asphalt impregnated fibreglass felts are non-hygroscopic, if left unprotected, the accumulation of moisture on their surface can lead to poor adhesion when applied.

The contractor must also be aware of the different application techniques between the two types. Organic felts should always be broomed so that any entrapped air or gas can be eliminated during their installation. As they are strongest in the machine direction they should be installed perpendicular to the long joints of the underlying insulation. The shrinkage and expansion of organic roof membranes in the cross machine direction is twice that of the machine direction. If the number of joints, including insulation, in each direction is taken into account, the potential for movement is four times as great in the cross machine direction as in the machine direction.

Fibreglass felts require different installation techniques than organic felts. Due to their porosity, they should be laid in such a manner that they are not subject to any foot top or vehicular traffic or other forms of point loading when being laid. Excessive pressure will literally squeeze out the soft bitumen between the layers causing a permanent void. Due to their strong memory, all fishmouths and wrinkles should be immediately cut out and removed. Also, they should be cut in place otherwise their strong memory will cause the membrane to dislocate at hard corners or projections. For this reason, they should never be used as membrane flashings at walls, parapets and curbs. Fibreglass felts do not require, nor should they, be broomed in. If glaze coating is required, it should be applied at minimum rates and with a light squeegee.

Organic and fibreglass felts have different coefficients of thermal expansion. At cold temperatures, these differences are too large to combine them in the field of the roof. Adding to the problems associated with mixing the two materials is the potential incompatibility of factory coating and saturating asphalts.

Insulations

In additions to providing the thermal function of the roof, insulations also act as the support for the membrane. The roofing contractor must be aware of the limitations of the material and be careful to avoid any damage during storage, handling and application. Certain insulations are prone to damage in contact with hot asphalts. If they are to be used, the roofer must use what is called the mop and flop technique. In this instance a fibreboard overlay is usually mopped on one side with the asphalt. Once cooled, it is placed onto the insulation surface. Care must be exercised to ensure that the asphalt has cooled sufficiently to prevent damaging the insulation, but not to the extent that good adhesion cannot be obtained. Careful positioning is also required to ensure no gaps in the cover board joints.

Many cellular foam insulations are available with a wide variety of facings for a particular application. Using a material with the improper facing for the particular membrane application can be catastrophic. Polyisocyanurate manufacturers have gone so far as to produce boards with a different facing on each side of the board. One, for conventional BUR roofing, is perforated to allow for venting of gases during application while the one for single-ply membranes is non-perforated. The contractor must ensure that the material is applied with "the right side up". Care must be exercised when installing single-ply membranes over certain insulations. Some are prone to chemical attack from the adhesives used in seaming. Others will deteriorate rapidly under the heat of a hot air welding gun or propane torch. Many of the problems associated with the application of roofing membranes over insulations can be greatly reduced or eliminated by incorporating a coverboard, such as a thin layer of wood fibreboard or perlitic insulation.

Under BUR membranes, cellulosic coverboards can reduce blister formation by providing a medium for the dissipation of vapourized moisture. It will also reduce the risk of damage and crushing of the insulation during installation or post construction roof top traffic. These same principles apply when a modified bitumen membrane is used, especially when the cap sheet is applied by torching.

Coverboards serve to protect the insulation from damage under single ply membranes. Significant reductions in the thermal resistance of some insulations can occur as a result of damage during their installation. This is especially true for loose laid systems where large quantities of ballast are placed on the membrane. A suitable coverboard will minimize potential facer delamination and foot traffic damage in fully adhered single-ply systems. The coverboard will also provide separation, resistance due to wind and thermal loading during the service life of the roof.

In mechanically fastened systems maintaining the proper clamping force between fastener plate and the underlying insulation in critical. Some insulations will suffer creep or plastic flow under continuous loading. This can be avoided by using a suitable creep resistant coverboard. The CRCA, and many manufacturers strongly recommend the incorporation of a suitable coverboard material in most low slope roofing assemblies.

Elastomeric Roof Coverings

Elastomeric roofing membranes have been in use in North America since the early 1960's. The most popular of these is EPDM (Ethylene Propylene Diene Monomer). Although widely used in a variety of configurations, their misapplication continues to be a source of problems on project sites.

Is it well known that the most vulnerable part of these roofing systems is at the field applied seams. As the membrane is a thermoset, it arrives at the site in a cured or vulcanized form. This means that it cannot be welded like a plastic sheet. Rather it relies on glues, seam tapes or a combination to produce a secure and watertight seam. Care and diligence during application of the seams is critical to their performance. Dr. W. Rossiter, of NIST, has demonstrated that sufficiently thick quantities of adhesive must be applied to obtain the required seam strength.[9] In addition, the mating surfaces must be thoroughly cleaned of all dust, processing talc or other contaminants to prevent bond failure.

The roofing contractor must be acutely aware of how climatic conditions may affect the curing of the adhesive. At cold temperatures, evaporation of the volatiles may result in condensation at the surface, compromising the integrity of the seam. There is a small, yet precise, window of application for most adhesives from which the contractor cannot deviate.

Poor planning and preparation can be disastrous. EPDM membranes have "memory" and the membrane must be conditioned prior to installation. This normally consists of unrolling the membrane and allowing it to relax for a prescribed period of time to dissipate the internal stress from manufacture.

There has been much discussion regarding recent publications by NRCC/IRC and NRCA on the subject of shrinkage of EPDM membranes. This phenomenon is generally manifested in tenting or pulling away of the membrane at perimeters and edges. In some instances, it has resulted in tearing of the membrane and leakage. If one reviews the research material one will see that these problems can only be avoided by ensuring sufficient securement of the membrane at the perimeters and openings. Perimeter fastening must be designed to have sufficient strength to resist the loads resulting from the membranes shrinkage over time.

Thermoplastic Materials

Recently, a host of new thermoplastic materials have been introduced in the roofing market. Like the more traditional PVC materials, the seams of these products are constructed by welding the laps, either by hand or by machine. For either technique, the skill of the installer is paramount. In handwelding, exact temperatures are required to ensure sufficient flow at the welds and to prevent burning of the membrane. In machine welding, the welding apparatus must be exactly calibrated to avoid under or overwelding. In both techniques, the applicator must carefully regulate the speed of operation and the weld temperatures. Climatic conditions, ambient air temperatures, shading and wind chill must be taken into account as they will significantly affect the integrity of the finished weld.

All single-ply membranes, elastomeric or plastomeric, are relatively thin sheet materials. Decks must be properly prepared (e.g., smooth and dry) to prevent damage and abrasion. Care in installation is crucial, otherwise tears and punctures may occur.

The contractor must also be knowledgeable with respect to the chemical resistance of these materials and their compatibility with other materials in which they may be in contact. Bituminous materials, such as asphalt and coal tar plastic cement will adversely affect both EPDM's and PVC's. Fully adhered PVC's should never be applied to pressure treated lumber. This is not due to incompatibility of the membrane itself with wood preservatives but because of the reactions with the membrane adhesive. Insulations with bituminous facers must be covered with a separation sheet to avoid contamination of the membrane.

Modified Bitumen Membranes

Modified bitumen membranes are an outgrowth of traditional asphalt technology combined with polymeric formulations and the factory assembly of single-ply membranes. These products have become popular primarily because of the uniformity derived from their factory assembly (i.e., uniform thickness, surfacing, etc.) and the addition of polymer modifiers result in better weathering and flexibility properties than traditional asphalts. The most widely used products contain either SBS (Styrene Rutadiene Styrene) or APP (Atactic Polypropylene) modifiers although other modifiers, such as POA (Polyalphaolefine) are now being used.

The properties of the products depend on the polymer modifier. Thus, the properties may be radically different. The contractor must, therefore, employ the appropriate installation methods.

SBS must be covered at all times because of its low UV and ozone resistance. Scuffing, abrasion, or any damage to the protective surfacing during installation must be repaired to avoid accelerated deterioration at those locations. APP membranes are generally more UV resistant. However, research by NRCA has shown that coatings, either field or factory applied will prolong their service lives. APP's are generally torch applied. Being a thermoplastic material, asphalt does not supply enough heat to remelt APP. SBS membranes can be both torch applied or mopped with hot asphalt. APP's should not be installed below 5°C and at cool temperatures (±10°C) they may require special application techniques. Because of its flexibility, SBS can be installed at low temperatures. If mopped, however, the temperature of the mopping asphalt must be at least 205° at point of application to melt the modified asphalt.

As with most single-plies, the vulnerable areas of modified bitumen systems are the seams. Seam integrity should be checked with a cold trowel while work progresses. Unbonded areas should be corrected by heat welding at the end of each day. Phased construction should not be allowed under any conditions. Laying the base sheet and returning at a later date to apply the cap sheet can result in moisture problems, yielding poor adhesion and blistering.

Special techniques are required for installation at low ambient temperatures to ensure adequate adhesion. Rolls should be stored in a dry heated area. On concrete decks, heating the substrate with a torch while applying the roll may enhance adhesion. As the reinforcements of these rolled goods have memory, they should always be rolled out prior to application and allowed to relax prior to their installation.

The skill of the application of these products is crucial, not only to achieve optimal performance but also to minimize the hazards and risks associated with open flames and hot asphalt. Under-torching of the rolls will result in poor adhesion and unbonded seams. Over-torching will damage the membrane reinforcement and asphalt. In mop applications, correct asphalt temperatures are required to melt the roll's undercoating and achieve full adhesion.

CONCLUSIONS

The industry continues to debate whether roofing is an art or science. The service embodied in product development, material manufacture, engineering and design has resulted in a host of high performance and durable roof products. Extensive research by material and building scientists has increased our understanding of both the physical characteristics of these materials, their behaviour in service and their performance requirements. The art, as embodied in the craftsmenship of the skilled tradesperson that installs the roofing product, is instrumental in building a reliable roof that will provide the consumer with its full expected value. Each party involved with the construction of the roof must assume responsibility on its performance, and each must fully comprehend its requirements and limitations. Errors or ommissions committed in a roof's initial construction will invariably have negative consequences for its performance. Even small defects in its initial construction may result in a significantly shortened service life or high remedial costs in the future. Careful planning, based on a sound understanding of good roofing practices and a thorough knowledge of the materials to be used is critical in building roofs to last.

REFERENCES

1. Tobiasson, W., "Vapour Retarders for Membrane Roofing Systems." Proceedings of the 9th Conference on Roofing Technology, NRCA, Chicago: 1989, p. 33.
2. Turenne, R.G., "Shrinkage of Bituminous Roofing Membrane." Canadian Building Digest, Division of Building Research. Ottawa: July, 1976.
3. Paroli, R.M. *et al*, "Shrinkage of EPDM Roof Membranes: Phenomenon, Causes, Prevention and Remediation." Proceedings of the 11^{th} Conference on Roofing Technology, Chicago: 1995, pp. 90-110.
4. Smith, Donald J., "Performance of Roots Relative to Design Slope". Report to Central Mortgage and Housing Corporation. Ottawa: 1978.
5. Rossiter, W.J. and Mathey, .R.G., "Effect of Insulation on Surface Temperature of Roof Membranes." U.S. National Bureau of Standards, NBS TR 66-987, February: 1976.
6. Richards, D.E. and Mirra, E.J., "Does More Roof Insulation: Cause Premature Roofing Membrane Failure or Are Roofing Membranes Adequate?" Proceedings of the Symposium Roofing Technology, NRCA, Chicago: 1977 p. 196.
7. Turenne, R.G., "Joints in Conventional Bituminous Roofing Systems". Canadian Building Digest, National Research Council of Canada, Division of Building Research, Ottawa: January, 1979. pp. 202-1 to 202-4.
8. Laaly, H.O., "Effects of Moisture on the Strength Characteristics of Built-Up Roofing Felts". Roofing Systems- STP603, American Society for Testing of Materials, Ed. D.E. Brotherson, Philadelphia: 1976, pp. 104-113.
9. Rossiter, W.J. *et al*, "Effect of Adhesive Thickness and Surface Cleanness on Creep-Rupture Performance of Ethylene Propylene Diene Terpolymer (EPDM) Peel and Lap-Shear Joints". Roofing Research and Standards Development : 3rd Volume, American Society, for Testing of Materials, eds. Wallace, T.J. and Rossiter, W.J., Ann Arbor: 1994, pp. 123 to 138.