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MEMBRANE ROOFING SYSTEMS IN JAPAN

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SHORT HISTORY

The origin of the built-up roofing industry in Japan followed the creation of the U.S. industry by half a century. Asphalt roll roofing was first imported from the U.S. at the beginning of this century, and built-up roofing followed several years later. The first Japanese manufacturer started producing built-up roofing materials in 1913, under the guidance of a U.S. engineer. Built-up roofing systems held a monopoly until World War II, because they had no competition.

In the mid-1950's, however, sheet-applied and fluid-applied elastomeric membranes entered the Japanese market, and their growth in the last 20 years has steadily reduced the dominance of conventional built-up membrane materials. The current estimated breakdown for the Japanese roofing market is as follows:

- Built-up membranes, 70-75%
- Elastomeric and plastic sheets, 15-20%
- Fluid-applied membranes, 10-15%

Fluid-applied membranes made of polyvinyl acetate emulsion entered the market in 1955, seven years after Japanese manufacturers had started producing this material. It was soon replaced by emulsion of copolymer of vinyl acetate and acrylate or emulsion of acryl styrene resin. Neoprene/HYPALON was introduced from the U.S. in the mid-1950's and a new system featuring two-part polyurethane was developed in 1966.

Waterproofing sheet made of polyisobutylene was imported from Reinische Gummi-und Celluloid-Fabrik AG in West Germany in 1957, and the licensee began to market it in 1961. Vulcanized butyl rubber sheet was produced from raw rubber supplied by ESSO Chemicals under the guidance of an engineer formerly with the Carlisle Corporation. Roofing sheet made of plasticized polyvinyl chloride for railroad cars was developed at the beginning of the 1950's, and the sheet of other compositions has been used for roof covering and waterproofing in buildings since the beginning of 1960's. Another sheet of this type for waterproofing was introduced from Dynamit Nobel AG in West Germany at the beginning of this decade, and the licensee recently began to market it.

New insulations and decks introduced in the Japanese market - notably, rigid plastic foams and gas concrete planks - have aggravated problems of thermal movement. Because of their relatively high coefficients of thermal expansion/contraction, these new materials have promoted membrane failures from fatigue rupture. The ability to withstand these larger thermal movements has been recognized as an ever more important membrane property.

In response to this problem of thermal movements in the substrate, conventional built-up roofing membranes have been improved through the use of synthetic fibers, which improve the felts' fatigue strength and elongation rate at breaking load.

BUILT-UP ROOFING SYSTEM

Built-up roof membranes have been greatly improved in their mechanical property by introducing synthetic fibers into roofing felts. VINYLON Is the trade name of polyvinyl alcohol fiber that was originally developed in Japan. About 20 years ago, VINYLON was introduced as an asphalt roofing base. Woven fabrics were tried first, but these early VINYLON felts shrank excessively in service. Several years later a roofing pioneer developed non-woven fabrics of long fiber. These non-woven fabrics solved the shrinkage problem, as demonstrated by the performance of observed roofs. Over the past 10 years, asphalt felts with VINYLON base have increased their sales in the domestic Japanese market. The production technique was exported to Europe, where the licensee supplied from Japan is marketing the product.

Following the success of VINYLON-roofing, other synthetic fibers - e.g. polyester, polypropylene, etc. - have been used as the fiber matrix of asphalt roofing felt. These synthetic-fiber felts are characterized by their larger elongation rate at break, and excellent fatigue resitance. (Load-strain properties of the several products in the market are illustrated in Fig. 1.)

Since built-up roofs are installed by hand in Japan, asphalt roofing felts can be easily laminated with other types in a membrane. In most three-ply membranes, one ply of synthetic-fiber felt is sandwiched between two plies of rag-base felt. In another arrangement, two synthetic-fiber felts are put in the second and third plies for greater strength. The asphalt roofing felt of synthetic fiber base is regarded as a principal constitutent in a built-up membrane. It must carry stress induced in a membrane by substrate movement. Substrate movement induces the largest strain in the bottom felt ply, with reduced strains in upper plies according to my strain analysis. Strains in the various plies depend upon their rigidity and also on stiffness and thickness of bonding asphalt. Thus if a felt of less rigidity is substituted for one of three plies of rag felts, the same thermal movement induces larger strains in the two remaining plies. In other words, if some plies in a multi-ply felt bitumen membrane are replaced by less rigid ones, higher stresses are concentrated in the remaining plies, and their strains consequently increase. This is the reason why 3%-tensile load is prescribed, as well as strength, elongation at break, etc. in the recently promulgated Japanese Industrial Standards (JIS), for this type of asphalt roofing felt.

Also over the past 10 years, Japanese roofing practice has been following European practice in spot bonding by perforated felt. The JIS prescribes two types of perforated felt:

- perforated asphalt-saturated and coated felt of rag base
- glass fiber or asbestos base with mineral surface

The former is used in spot-bonding of protected membranes; the latter (because of its excellent dimensional stability) in membranes finished with mineral-surfaced roofing felt.

Japanese water-pollution controls are accelerating the trend toward synthetic-fiber felts. Production of rag and paper felts requires great quantities of water, and this water must be treated before discharge into rivers. The expense of this pollution control has accelerated the switch from organic to synthetic or glass fibers, used not only in perforated felt, but also in asphalt roofing felt surfaced with powdered asphaltite or mineral granules.

Like the European, the Japanese roofing industry prefers asphalt of drastically higher viscosity than the U.S. industry. (In contrast with the permissible U.S. softening-point range of 135°F-225°F, minimum for ASTM Type I to maximum for ASTM Type IV, the permissable Japanese softening point ranges from 184°F or 85°C with no prescribed maximum - see Fig. 2). The greater mechanization of the U.S. field practices - pumping of asphalt onto roofs and use of mechanical felt layers - provides at least a partial explanation of the U.S. preference for lower viscosity bitumen. In Japan, manual methods prevail: hot asphalt is hoisted by bucket and poured with a ladle, and felt is unrolled by hand. There are also some technical differences between U.S. and Japanese roofing practice, and these help to account for the difference in preferred bitumen viscosities.

ELASTOMERIC AND PLASTIC SHEETS

Polyisobutylene (PIB) sheet was first imported from West Germany in 1957, and the Japanese licensee began to market it in 1961, for use in waterproofing of underground structures and water reservoirs. At that time, fatigue rupture of built-up roof membranes caused by substrate movement was often observed, and recognized as one of the most important problems for roof covering. The high elongation rate of PIB sheet unfortunately misled architects and engineers to apply it as fully bonded roof coverings. It was often installed on thermally mobile substrates, such as wood wool or gas concrete planks fixed on steel truss frames, or the like. On these expanding-contracting substrates, the sheets often ruptured along stress-concentration lines at joints between planks. These failures demonstrated the architects' and engineers' ignorance concerning proper use of PIB sheet, rather than the poor fatigue resistance of the sheet.

Shortly after the appearance of PIB sheet, a competitor began to produce vulcanized butyl rubber (IIR) sheet in 1962. It proved soon, however, that the sheet easily cracked within a few years after installation on roofs, because of poor resistance against ozone. The IIR sheet was improved by blending ethylene-propylene terpolymer (EPDM) two years after it entered the market. Since then vulcanized IIR/EPDM sheet has become the most popular elastomeric and plastic sheet in Japan.

There are three types of vulcanized IIR/EPDM sheets on the market. One, without backing, is bonded to substrates by applying adhesive on the surfaces of substrate and sheet. A second, backed with unvulcanized rubber sheet, is bonded to the substrate by applying adhesive only on the surface of substrates. The third, laminated with self-adhesive layer, is bonded on primed substrates by roller pressure.

The latter two types are effective for reducing stress caused by substrate movement. They are, however, less resistant to shrinkage. Asbestos backing helps these sheets to resist shrinkage stresses, however, it is little used, possibly for economic reasons.

Joint splicing between sheets is the most critical field operation. Failure in joints of single-ply membranes causes leakage. Single-ply sheet membranes cannot, therefore, be generally regarded as reliably watertight as built-up or fluid-applied systems.

One response to this problem was unvulcanized rubber sheet, made of reclaimed butyl rubber, developed for the purpose of making more reliable joints. It has been used for waterproofing in protected roofs.

A roofing sheet made of plasticized polyvinyl chloride (PVC) for railroad cars was developed at the beginning of 1950's, and almost at the same time, a floor covering sheet of plasticized PVC was also produced. The floor covering sheet was used, on one occasion, for a laboratory using radioactive isotopes. Floors of the laboratory must be washed to remove radioactive contamination; the sheets were thus bonded on substrates with adhesive, and joints between the sheets were heat-welded for the purpose of waterproofing. This system of welded joints was used on the roof of a dining room as a trial, as a roof covering system for light traffic. After several years' observation, the manufacturer began to market this system, and the sheet was improved for outdoor use.

Other plasticized PVC sheets, used for waterproofing of protected membrane roofs and underground structures, have appeared in the roofing market over the past 15 years. Another sheet was introduced from West Germany at the beginning of this decade, and the licensee began to market it recently.

Other high polymeric materials—notably chloroprene rubber, HYPALON, copolymer of ethylene and vinyl acetate, polymethyl-methacrylate, rubberized asphalt, and polyvinyl floride - have also been investigated as roof coverings and waterproofing sheets over the past 10 years. Some are expected to succeed; others appear destined to disappear.

FLUID-APPLIED ROOFING SYSTEMS

Of the many fluid-applied systems introduced into the Japanese market over the past quarter century, a continuing elimination process has defined acceptable conditions for their use. The history of polyvinyl acetate emulsion illustrates the process. Soon after its appearance in 1955, it was replaced by copolymer of vinyl acetate and acrylate. A few years later, acryl styrene resin or polymethyl-methacrylate was introduced for this purpose and has been used more than fifteen years. Emulsion of these resins is brush-applied on roofs with reinforcements such as woven or non-woven fabrics in order to improve the movement capability and to control the thickness of the membranes. Even with reinforcement, these membranes don't adapt well to thermal movement. Their use is thus limited to roofs and eaves less subject to thermal movement.

Neoprene/HYPALON has its limitations. First imported from the United States around the time of the first application of polyvinyl acetate emulsion, this system was expected to provide bright, reflective coatings for roofs with curving surfaces that are prominent building features and thus esthetically important—domes, barrel shells, hyperbolic paraboloids, etc. Although sections of the curved shells are in compression, theoretically precluding cracking, shells often crack from drying shrinkage of concrete or uneven settlement of foundations. Thus, contrary to expectations, membranes on these roofs often rupture. These failures may result from one or more of the following: poor materials, poor specifications, or lack of structural precautions.

Since its introduction some ten years ago, a two-part polyurethane system, featuring membrane flexibility and application speed, has captured the largest share of the fluid-applied roofing market. Flexibility derives from the nature of polyurethane rubber, and fast application from the two-part composition, which enables the applicator to build membranes to required thickness with just a few coats. These membranes are reinforced with fabrics, depending on the particular membrane requirements.

This popular fluid-applied system does, however, have several drawbacks. Repairs are undependable, because the two-part polyurethane mixture does not adhere well to weathered surfaces, even of the same material, unless the surface has received elaborate preparation. Moreover, the ability to resist thermal movement remains poor until the fluid polyurethane has completely cured. Thus these membranes are vulnerable during the application operation.

Mixed asphalt-rubber emulsions have entered the Japanese market for waterproofing of roof membranes and underground structures. Because of their poor weathering qualities and their black color (which increases roof temperature in hot weather), these materials should not be exposed to sunshine. The first asphalt-rubber emulsion system, imported from West Germany in 1967, is applied through two or more nozzles, with one or two precipitant sprays hardening emulsion spray from another nozzle. As its chief advantage, this system forms a thick membrane in a single operation.

A similar Japanese-developed system features an emulsion with up to 85% solid content—usually brush-applied, with or without a mixed precipitant. It, too, carries the same restrictions as the West German system. Still another sprayed emulsion of colored acrylic has been used for self-finished roof membranes and for waterproofing exterior wall surfaces.

NEW BUILT-UP ROOF SYSTEMS

The same factors that helped stimulate the development of sheet and fluid-applied elastomeric membranes - shortage of qualified built-up roofing workmen, anti-pollution regulations and fire risks - have promoted development of new built-up roofing systems in Japan. Among these new built-up roofing systems are:

- membranes laminated by heating thick asphalt interply applications with hot air (like a similar European system featuring propane-torch heating)

- membranes laminated by asphaltic adhesives
- membranes laminated with pressure-sensitive roofing sheets, on one or both adhered surfaces. (This system was recently exported to Europe.)
- Two-layer system of high quality roofing sheets: twin roofing felts of synthetic fiber base, laminated roofing felt with plastic film, or elastomeric sheet, with or without self-adhesive layer. (This system can be rapidly installed, but is troubled by the inherent problems of the conventional built-up system.)

Although the systems above mentioned do not solve all the aforementioned problems some are expected to succeed in the Japanese roofing and waterproofing market.

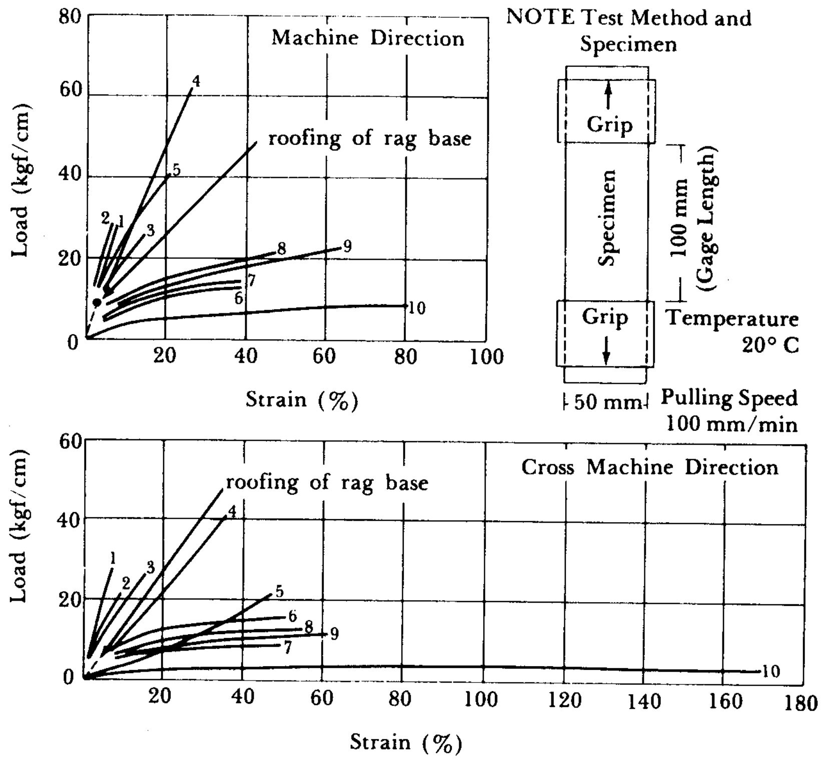
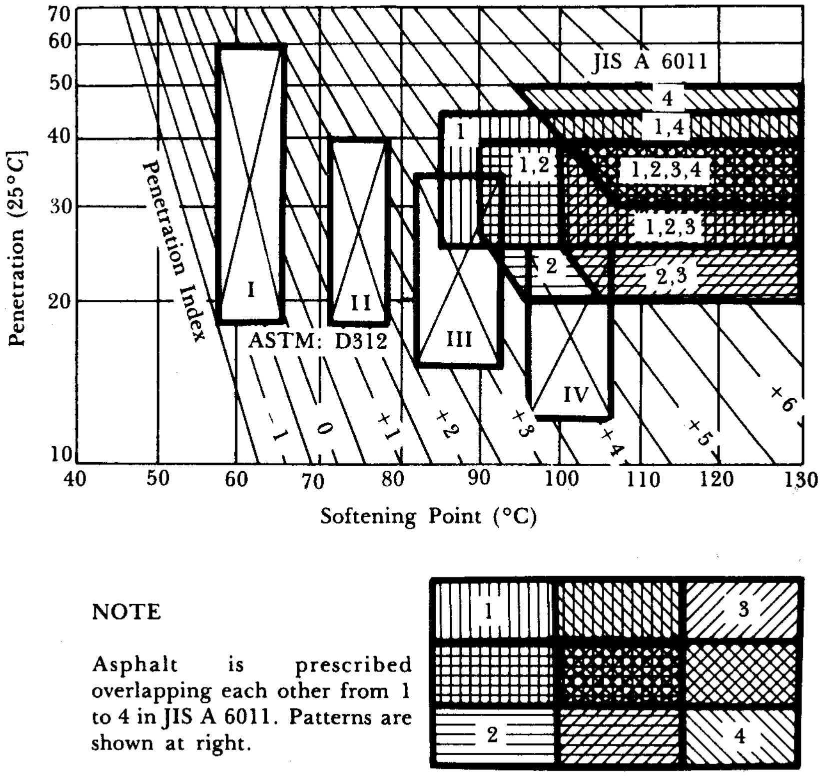


FIGURE 1 - LOAD-STRAIN PROPERTIES OF ASPHALT ROOFINGS OF SYNTHETIC FIBER BASE



NOTE

Asphalt is prescribed overlapping each other from 1 to 4 in JIS A 6011. Patterns are shown at right.

FIGURE 2 - PENETRATION AND SOFTENING POINTS OF ASPHALTS PRESCRIBED IN THE ASTM AND JIS