Review of Residential Roofing Materials, Part II

A Review of Methods for the Manufacture of Residential Roofing Materials

by Hashem Akbari, Ronnen Levinson, and Paul Berdahl, Heat Island Group, Lawrence Berkeley National Laboratory

INSPECTING THE FINISHED PRODUCT AT A CLAY TILE PLANT.

Production of shingles. Fiberglass asphalt shingles have three major components: fiberglass mat, asphalt (with additive fillers), and granules (colored and uncolored). In a typical plant, the fiberglass mat is fed into a roll coater that applies layers of stabilized coating asphalt to the top and bottom surfaces of the webbing sheet. Stabilized coating asphalt is harder and more viscous than straight asphalt, and has a higher softening point. The mineral stabilizer may consist of finely divided limestone, silica, slate dust, dolomite, or other minerals.

The "filled" or "stabilized" coating asphalt applied at the coater is produced in the mixer, which is usually positioned above the manufacturing line at the coater. Coating asphalt, typically at 200-270°C (400-520°F), is piped into the mixer, and the mineral stabilizer is added. To eliminate moisture problems and to help maintain the temperature above 180°C (360°F) for proper coating consistency in the mixer, the mineral stabilizer is dried and preheated before being fed into the mixer.

The weight of the finished product is controlled by the thickness of coating asphalt used. The coating rolls can be moved closer together to reduce the amount of coating applied to the substrate, or separated to increase it. Most modern plants are equipped with automatic scales or profile scanners that monitor the sheets during the manufacturing process and warn the operator when too much or too little coating is being applied.

Colored and uncolored granules are applied in a section of the manufacturing line that usually consists of a multi-compartmented granule hopper, two parting-agent hoppers, and two large press rollers. The hoppers are fed through flexible hoses from one or more machine bins above the line. These machine bins (sometimes called surge bins) provide temporary storage. The granule hopper drops colored granules from its various compartments onto the top surface of the moving sheet of coated web in the sequence necessary to produce the desired color pattern on the roofing.

Next, the sheet is cooled by passing it over water-cooled rollers; water may also be sprayed directly onto the sheet to speed cooling. The final steps in the production of asphalt roofing shingles are cutting and packaging. After the shingles have been cut by machine they are moved by a roller conveyor to automatic packaging equipment. The packaged shingles are then stacked on pallets and transferred by forklift to storage areas or waiting trucks.

Clay tiles. Clay tile production begins by mixing and crushing various raw clay materials. For example, the raw clays used at MCA include "yellow shell clay" (a highly refractory clay [i.e., having high heat resistance, permitting vertical firing without warping] with medium plasticity); "apple clay" (a weakly refractory clay with high plasticity); and "AAA clay" (a medium refractory, low shrinkage clay with high iron content to make the tile red).

The raw clays are thoroughly mixed with water and aged for 4-5 days. The aging process allows the dry material to absorb the moisture fully, improving plasticity. This increases yields from the extrusion process and thus lowers the unit production cost.

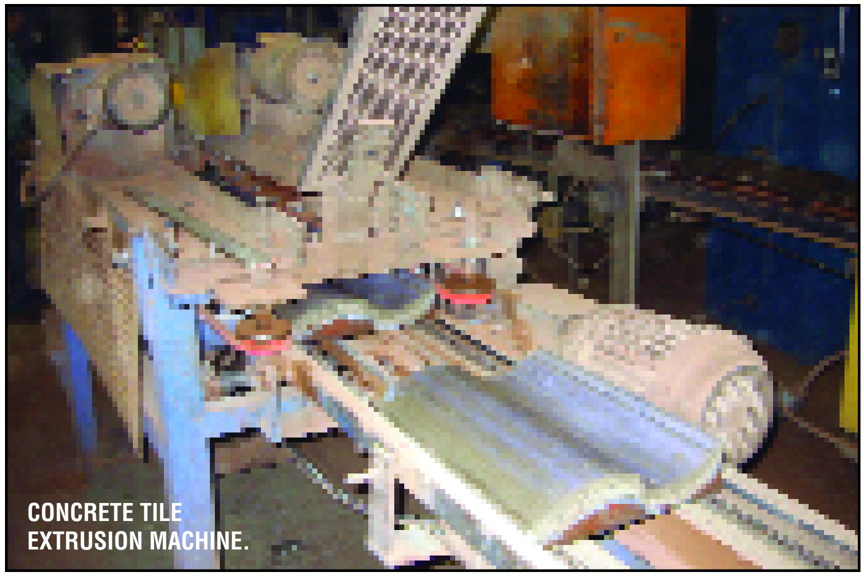
Several extrusion machines and dies are employed to produce clay tiles of various shapes. Prior to extrusion, the clay flows through a vacuum chamber to remove air, preventing cracking of tiles during the firing process. This process is also very important for proper vitrification (conversion to a glassy state), which makes the tile weather-resistant (i.e., resistant to freezing/thawing and salt intrusion) [See Clay Roof Tile Specifications: ASTM C-1167 for more detail]. An automated cutter at the end of each extruder cuts the tile to desired size, and trims the edges. The wet extruded tile is then dried in a sequence of temperature-controlled chambers for about 24 hours. By reducing the excessive moisture in the tiles, this drying process will reduce the probability of cracks when the tile is fired. The drying process typically starts with circulating ambient air at a temperature of about 20-30°C, gradually increasing the temperature to about 90°C using waste heat from the kiln-cooling process. Drying reduces the tile's moisture content from 15% to less than 1%.

(Continued on Page 54)

Review of Residential Roofing Materials, Part II

(Continued from Page 52)

The dry raw tiles are inspected for defects before they are sprayed with glossy or matte glazes. The glazing is a mixture of water, pigments and clay additives. For the glossy finish, frits (glassy silicates), clay, and color-glazed materials are added to the glazing mixture. The glazed tiles are positioned in vertical stacks or in a "standing up" position, with typically 1.25 cm (½") spacers to allow an even heat distribution in the kiln. Even heating yields evenly colored tiles with good mechanical properties.



CONCRETE TILE EXTRUSION MACHINE.

The glazed tiles are then passed through a kiln, fired for 14-20 hours, depending upon the production schedule. The kiln has three stages: preheat, heating, and cooling. In the preheating zone, the tiles are gradually heated to about 700°C by warm drawn air from the heating zone. In the heating zone, the tiles are directly fired for about four hours by gas flame, reaching a maximum temperature of about 1050°C. Then the tiles are gradually cooled to about 300-400°C by drawing outside air through the kiln. The clay tile is ready to ship as soon as it is removed from the kiln - no curing is required. The clay tile colors are permanent and do not fade with exposure to the sun.

Concrete tiles. Sand, cementitious materials, limestone fillers, and water are the main ingredients (by mass) of concrete tiles. Pigments are added for color and polymers are used as a water-resistant coating on the tile surface. Pigments are typically added to the surface in a slurry coat comprised of pigment, cement, silica and water. Finished concrete tiles may also be painted. The major components contributing to the cost are cementitious materials, sand, polymer coating, and pigments.

Concrete tile production begins by mixing aggregate (sand) and fillers. Sand is pre-washed to remove dirt contaminants. Recycled aggregates and quarry waste are also used in the mixture, and milled calcium carbonate is used as filler (calcium carbonate filler is an inexpensive material that improves the quality of concrete). Then the aggregate and filler mix are mixed with cementitious materials before water is added to the mixture. The percentages of calcium carbonate filler added to the mix vary from facility to facility. At this stage, pigments may be added to color the concrete mix. The ingredients are completely mixed before being fed to the molding machine.

Several machines and molds are employed to produce concrete tiles of various shapes. The mold and the wet concrete tile run on a conveyor where the tiles are partially dried and polymeric coating is applied to the surface before curing. The tiles and the mold are packed in a curing chamber for about four hours, where the concrete tile is cured and dried. The molds and tiles run through a separator that removes the molds from the tiles. The dry raw tiles are inspected for defects before they are sprayed with colored coatings. The tiles are then covered with post-coating polymers. The coating is a mixture of water, pigments, and polymeric additives. The coated tiles are then dried, stacked, and packed for shipment.

Metal Roofing. Metal production for the roofing industry may be divided into two phases: (1) metallic and/or coil coating plants, where raw metal coils are cleaned, metallic coated, primed, and coated with paint (some facilities can both metallic-coat and paint, while others only apply paint); and (2) metal-forming plants, where the coated coils are either used to produce flat metal panels, or pressed into shapes that simulate non-metal roofing products (e.g., shake, slate, or tile).

Coil Coating Plants. Coil coaters produce rolled metals in the thickness, width, metal-coating type, and color specified by their customers, which include but are not limited to members of the roofing industry. An advanced metal coil plant typically has four major production lines: a *pickle line*, where the hot band coil (hot band coils are the result of steel slabs being elongated and rolled into coiled sheet of finite width and thickness; the temperature and amount of processing determine mechanical properties of the coil) is uncoiled and cleaned of oxides, edges are trimmed to customer requirement, and the coil is oiled in preparation of further processing; a *cold mill line,* where the pickled bands are reduced in thickness 65-80% to meet ordered thickness, and rolled to a suitable shape, and texture is applied to the surface; a *metallic coating line*, where the coils are cleaned again, a layer of metallic coating is applied, and the surface is treated for either painting or bare metal application; and a *paint line* where primer and finish coatings are applied. Many coil coaters consist of only a paint line; they do not process their own substrate. In addition to steel, aluminum can also be coated via the coil process.

Pickle line. The raw material for this industry is typically a thick metal steel coil. The hot-band coil is pickled when it first arrives at the coating plant. There it is uncoiled and cleaned in a series of acid baths to ensure the proper surface for further processing (cold rolling and galvanizing [coating with zinc] or galvalumizing [coating with a zinc/aluminum alloy]). The steel is then side-trimmed to the customer's specifications for width. At the end of the pickle-line process, the steel is re-coiled and ready to go on to the cold rolling mill. The pickle line is capable of continuous production. One coil is processed while the other is prepared to be fed to the line.

Cold Mill Line. In the cold-reversing mill (CRM) line, the thickness of the metal coil is reduced to specification by repeatedly passing through pressure rolls. Larger-scale cold mills will have four or five "stands" in a row that the strip passes through. This way the full gauge reduction is achieved with one pass.

Metal Coating Line. In the metal coating line, the steel coils are cleaned again, a layer of metallic coating is applied, and the surface is treated either for painting or for use as bare metal. Coils from the cold mill line are fed to the system and welded together for continuous-line operation. The coil then passes through an accumulator tower; the steel coils are cleaned in preparation for the metallic coating before being fed to the annealing furnace to achieve the desired mechanical properties. Coming out of the furnace, the strip is directly dipped into a molten bath of zinc or galvalume. The specified coating weight is achieved by air wiping excess metal before it solidifies. The hot-coated coil is then cooled and treated with a surface-conditioning mill, the process is very similar to the cold mill, but on a much smaller scale as gauge reduction is not the goal, simply a smooth surface. The steel is slightly elongated for uniform flatness by the tension leveler. The surface can also be chemically treated and coated with a resin for bare-metal applications.

Paint Line. The paint line is similar to the metal coating line. In the paint line, a coil from the metal-coating line is fed to the system where coils are welded or stitched together for a continuous operation of the line. Then the coil passes though an accumulator tower and cleaner prior to chemical coating. The chemical coater pre-treats the surface to accept primer or paint and to provide corrosion resistance. A primer is then applied to the steel strip and cured in the prime oven. Then the strip is coated with the finish paint and cured in the finish oven. Paint lines have the ability to paint only one or both sides of the strip, depending on customer requirements. The cured, painted steel is then quenched with water and cooled to room temperature. Finally, rollers remove the excess water, and the steel goes into the exit accumulator before it is taken up onto an exit reel. The finished strip can be sent back through the paint line if additional paint layers are desired. This is often done for print or pattern finishes where the final product consists of multiple colors that can mimic wood shakes, asphalt shingles or aged copper.

Metal Forming Plants. Metal forming plants cut and press painted or unpainted metal coils to form either flat panels or simulations of non-metal roofing products (e.g., shake, shingle, tile, and slate). A very few fabricators

(Continued on Page 56)

Review of Residential Roofing Materials, Part II

(Continued from Page 55)

apply granulated material to the painted panels in order to simulate asphalt shingles. However, most fabricators of shingle or tile-type profiles use embossing or stamping to achieve the desired look.

Methods to Produce Cool Roofing Materials

- *Shingles.* The solar reflectance of a new shingle is dominated by the solar reflectance of its granules, since by design the surface of a shingle is well covered with granules. Hence, we focus on the production of cool granules. There are primarily two ways to increase the solar reflectance of the granules: manufacturing granules from highly reflective (e.g., white) rocks, and/or coating the granules with reflective pigments. The use of naturally white rock is limited by local availability of suitable inert rocks, which are often not found in large quarries. Hence, manufacturers usually color the granules.

Until recently, the way to produce granules with high solar reflectance has been to use titanium dioxide (TiO_2) rutile, a white pigment. Since a thin layer of TiO_2 is reflective but not opaque, multiple layers are needed to obtain the desired solar reflectance. This technique has been used to produce "super-white" (meaning truly white, rather than gray) granulated shingles with solar reflectances exceeding 0.5. Manufacturers have also tried to produce colored granules with high solar reflectance by using non-white pigments with high NIR reflectance. However, like TiO_2, cool colored pigments are also partly transparent to NIR light; thus, any NIR light not reflected by the cool pigment is transmitted to the (typically dark) granule underneath, where it can be absorbed. To increase the solar reflectance of colored granules with cool pigments, multiple color layers, a reflective undercoating, and/or reflective aggregate should be used. Obviously, each additional coating increases the cost of production.

A conventional black roof shingle has a reflectance of about 0.04. On the first try to increase the solar reflectance of the shingle, we replaced the standard black pigment on the granules with one that is NIR reflective. That increased the reflectance of the granule to 0.12. On the second try, we used a two-layered technique where we first applied a layer of TiO_2 white base (increasing the solar reflectance of the base granule to 0.28) and then a layer of NIR-reflective black pigment. This increased the reflectance of the black granule to 0.16. On our third prototype, the base granule was coated in ultra-white (reflectance 0.44) and then with a NIR-reflective black pigment. This increased the solar reflectance to 0.18.

The application of pigmented coatings to roofing granules appears to be the critical process step. Several layers of silicate coatings can be involved, and may include not just one or more pigments, but the use of clay additives to control viscosity, biocides to prevent staining, and process chemistry controls to avoid unreacted dust on the product.

One way to reduce the cost is to produce cool colored granules via a two-step, two-layer process. In the first step, the granule is pre-coated with an inexpensive pigment that is highly reflective to NIR light. In the second step, the cool colored pigment is applied to the pre-coated granules.

Shingles tend to lose some granules as they age and weather, exposing asphalt-coated fiberglass and reducing solar reflectance. Substituting a reflective sealant for the black asphalt could slow this. While developing such a replacement for asphalt may be of long-term interest, we do not see an easy solution to this problem.

It should be noted that the reflectance of an asphalt shingle covered with granules will be less than that of the granule's coating, since some of the light reflected by each granule will strike a neighboring granule and be absorbed. These "multiple reflections" can reduce shingle reflectance by as much as 0.15.

Finally, the granule manufacturing and shingle manufacturing industries have designed their quality-control laboratories to test the visible color of their products. We anticipate that the industry will need to equip itself with additional instruments to test the solar reflectance and the NIR optical properties of their products. It is also envisioned that unified standards have to be developed to address issues related to manufacturing of cool colored granules and shingles.

☗ *Clay tiles.* Options for production of colored tiles are similar to those of the roofing shingles. The three ways to improve the solar reflectance of clay tiles include: (1) use of raw clay materials with low concentrations of iron oxides and elemental carbon; (2) use of cool pigments in the coating; and (3) application of the two-layered coating technique using pigmented materials with high solar reflectance as an underlayer. Although all these options are in principle easy to implement, they may require changes in the current production techniques that may add to cost of the finished products. Colorants can be included throughout the body of the tile, or used in a surface coating. Both methods need to be addressed.

☗ *Concrete tiles.* There are three ways to improve the solar reflectance of colored concrete tiles. The first is to whiten the tile by using white cement in concrete mix; using a white cementitious surface coating (during the pre-cure coating); and/or or using white polymeric surface coating (during the post-cure coating). The second method is to use cool color pigments (infrared-scattering colored pigments) in the coating to provide choice of high-reflectance color. Examples of such cool colored pigments include mixed metal complex inorganic pigments. Cool pigments have been used successfully by a few leading and innovative tile-manufacturing companies. The third approach is to use cool pigments over a highly reflective undercoat. The undercoat must be allowed to dry properly before application of the topcoat. For example, phthalocyanines blue can be used in manufacture of

(Continued on Page 58)

Review of Residential Roofing Materials, Part II

(Continued from Page 57)

blue concrete tiles. In these prototypes, cool colored coatings are applied on a white base coat on concrete tiles.

Metal panels. Application of cool colored pigments in metal roofing materials may require the fewest number of changes to the existing production processes. As in the cases of tiles and asphalt shingle, cool pigments can be applied to metal via a single- or a double-layered technique. If the raw metal is highly reflective, a single-layered technique may suffice. The coatings for metal shingles are thin, durable, polymer materials. These thin layers use materials efficiently, but limit the maximum amount of pigment present. However, the metal substrate can provide some NIR reflectance if the coating is transparent in the NIR.

Quality control. The quality-control laboratories of colored roofing manufacturers are typically equipped to test the visual appearance (e.g., color) of their products. We anticipate that the industry will need to acquire instruments for testing the solar reflectance and NIR reflectances of their products. It is also envisioned that unified standards will have to be developed to address the initial reflectance, aged reflectance, mechanical properties, and thermal properties of cool colored roofing materials.

Conclusions

Fiberglass roofing shingles, tiles, and metallic materials comprise over 80% (by roof area) of the U.S. western region residential roofing market. In cooling-dominated regions, increasing the solar reflectance of the roofs lowers air-conditioning use in cooled buildings and improves comfort in unconditioned buildings. Our analysis has suggested that cool colored roofing materials can be manufactured using the existing equipment in production and manufacturing plants. The three principal ways to improve the solar reflectance of roofing materials are: (1) using raw materials with high solar reflectance, (2) using cool pigments in the coating; and (3) applying a two-layered coloring technique using pigmented materials with high solar reflectance as an underlayer. Although all these options are in principle easy to implement, they may require changes in the current production techniques that may add to cost and competitiveness of the finished products. Application of cool colored pigments in metal roofing materials may require the fewest number of changes in the existing production processes. As in the cases of tile and fiberglass shingle, cool pigments can be applied to metal via a single or a double-layered technique. If the raw metal is highly reflective, a single-layered technique may suffice. Additional quality-control measurements may be required to verify that coatings are truly NIR reflective.