Forensic Microanalysis of Building Materials

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The **Colosseum**, originally known as the **Flavian Amphitheatre**, is in the center of the city of Rome. Originally capable of seating 45,000–50,000 spectators, it was used for gladiatorial contests and public spectacles. Construction starting between 70 and 72 AD under the emperor Vespasian. The amphitheatre, the largest ever built in the Roman Empire, was completed in 80 AD under Titus. Its outer wall originally measured 545 meters and is estimated to have required over 100,000 cubic meters of travertine stone held together by 300 tons of iron clamps.

Abstract

Building materials expose a variety of particles that cross a diversity of well established microanalysis specialty areas such as coatings, polymers, fibers, and glass.

Primary and secondary transfer of building materials between individuals, tools, and weapons may occur during practically any urban crime. The examination of discharged bullets may help define bullet path including impact with intervening materials. Fibrous

insulation, gypsum wallboard dust, paint, glass, wood dust, etc. may transfer to a suspects clothing and hair during a burglary. Tools found in a suspect's possession may have building materials smeared or adhering to them which may offer important clues in an investigation. Motor vehicles involved in an accident may be an excellent repository of building materials from contact with an immovable object such as a concrete barrier or wooden utility pole. Traces of concrete, brick and engineered wood are often encountered as evidence. Introductory information on these topics is provided to gain insight into an underutilized microanalysis sub-discipline.

Portland Cement and Hardened Concrete

The development of Portland Cement is credited to an English mason, Joseph Aspdin in 1824, when he obtained a patent for a cement that reminded him of natural limestone quarried on the Isle of Portland in the English Channel. Portland cements are hydraulic meaning they set and harden by a chemical reaction with water known as hydration. When the paste, composed of cement and water, is added to aggregate such as sand and gravel, the paste acts as an adhesive and binds the aggregate together forming concrete.

Highways, sidewalks, walls, bridges, parking structures, bunkers, dams, barriers; hardened concrete is ubiquitous in our environment. The science behind the concrete is the cement, Portland Cement, a construction material composed of a fine gray powder made by finely crushing and grinding raw materials composed of appropriate proportions of calcium oxide, silica, alumina, and iron oxide. These materials generally originate from limestone, marl, chalk, clay, sand, and shale. Waste products, such as fly ash, can also be used as a silicon source. Iron and aluminum can be provided as iron ore and bauxite, and recycled metals can also be used. After blending, the raw materials are feed into a rotary cement kiln, one of the largest pieces of moving industrial equipment in the world. The kiln is a long, sloping cylinder that gets progressively hotter up to about 2700°F (1480°C). The raw materials in the kiln undergo complex chemical and physical changes producing a material known as clinker (figure 1). Reactions that take place in the kiln include the calcining of limestone (calcium carbonate) into lime (calcium oxide) and carbon dioxide, and the bonding of calcium oxide and silicates to form dicalcium and tricalcium silicates, tricalcium aluminate and tetracalcium aluminoferrite. The clinker is then pulverized to a fine powder with the addition of small quantities of gypsum. The relative proportions of these ingredients determine the Portland cement classification. The American Society for Testing and Materials (ASTM) Designation C 150, Standard Specification for Portland Cement, delineates eight types of Portland Cement chemically blended for specific usage.

Forensic examinations of hardened concrete are conducted to either compare questioned concrete samples to a known source for class characteristic similarities or to determine the source of the concrete. An effective way to geo-source hardened concrete is to examine the aggregate. The sand to pebble sized material is usually locally obtained and will suggest geologic locations where the concrete was manufactured. Some common case scenarios include; a) a body or body part is founded encased in concrete and a comparison to concrete residue on a tool is requested, b) examination of concrete residue on a bullet may help in determining bullet path at a crime scene, c) replacement cases, for example weapons are shipped and upon arrival concrete has replaced the weapons. An examination of the aggregate in the concrete may determine where the replacement occurred, d) what are the unique ingredients in the concrete that may aid in understanding what its used for and e) are their any health hazards such as the presence of asbestos within the concrete.

ASTM Designation: C 856-95, Standard Practice for Petrographic Examination of Hardened Concrete, delineates a microscopical approach to examining concrete with details on sample preparation, examinations using visual, stereobinocular and polarized light microscopy. Within the guideline are tables listing characteristics observed in concrete and optical data on secondary deposits in concrete. The book, *Microscopical Examination and Interpretation of Portland Cement and Clinker*, by Don Campbell, is the most important single reference to have available if you are to critically examine hardened concrete.

The examination of an intact piece of concrete should begin with the potential for a physical match and observation of any adhering traces such as blood, tissue, hairs and fibers. After a stereobinocular examination of the surface features of the concrete, a piece can be crushed and mounted in an immersion liquid for characterization by polarized light microscopy (PLM). But by far the best approach, sample size permitting, would be to prepare ground and polished specimens and thin-sections in the same way geological specimens are prepared (figures 2-3). For a crude first examination, start by grinding one surface with progressively finer grit and examine the ground surface with a stereobinocular microscope. For the preparation of thin sections a private lab or a university geology department may be of assistance. Some of the useful features to be examined by reflected polarized light microscopy are color, porosity, fractures, oxidation, aggregate composition, grain size and texture. A thin-section petrographic examination would include the examination of relict Portland cement grains, cement paste, hydration products, aggregate sand grain composition, matrix features, voids and any additives such as vermiculite, fly ash, perlite, etc. (figure 4). Interesting features to look for include air-entrainment voids, which are small air pockets less than three millimeters in diameter (figure 5). Chemicals/resins are added to the concrete during pour to produce bubbles, which when the concrete cures forms voids. Concrete with these features improve the resistance to freeze-thaw action and minimize the effects of chemicals applied to the concrete for snow and ice removal. Entrained-air features are usually not seen in North American concrete prior to 1940. Blended hydraulic cements can incorporate a variety of industrial by-products such as blast-furnace slag, kiln dust, and fly ash.

Bricks

Brick manufacturing follows the same basic steps performed for centuries. Clay and shale are the primary ingredients in brick. Bricks are produced by mixing raw clay that has been crushed, pulverized and screened with water. The clay is then formed into the desired shape, coated with glaze, then dried and fired. The firing phase can be divided into six general stages: evaporation of free water, dehydration, oxidation, vitrification, flashing and cooling. Clays are unlike metals in that they soften slowly and fuse gradually when subjected to rising temperatures. The fusibility of clay is what causes the clay to become hard. Many bricks have smooth or sand-finished textures produced by the dyes or molds used in forming. Many textures may be applied by attachments which cut, scratch, roll, brush or roughen the surface as the clay column leaves the die. A crime several years ago illustrates when the knowledge of brick composition can help in casework. A young boy was sodomized adjacent to a baseball park infield. The suspect was later arrested and his shoes examined for soil and compared to soil from the ball field. Traces of red brick were observed in the soil (figure 6-7). This particular city used crushed recycled red brick for the baseball infield. Microscopical examination of the brick particles showed similarities in both color, texture and composition.

Concrete or cement bricks are usually made by compressing a moistened mixture of Portland cement and sand into molds. A dry mixture permits the molds to be removed immediately. The brick is then steam cured or sprayed with water. Concrete block, also known as concrete masonry unit (CMU), is made of cement, aggregate and water. The blocks can be solid or hollow in a variety of designs. The aggregate can be gravel, crushed stone, air-cooled slag, coal cinders, expanded shale, clay, volcanic cinders, pumice, and/or vermiculite.

Engineered Wood Products

Engineered wood is a manufactured building material originating from a variety of wood and non-wood products bound together to form a composite. Wood strands, sawmill scraps, veneers, plastics, and non-lignin containing materials such as wheat straw and sugar cane residue are used along with adhesives to manufacture a wide variety of products.

Oriented strand board (OSB) such as Louisana-Pacific's Inner Seal Siding® is an example of engineered wood used for exterior siding. Inner-Seal Siding® and types known as Waferwood® are engineered wood products made from strands or wafers of wood. A mill starts with fast growing trees, such as aspen or pine. It runs those trees through a “waferizer” that cuts them into razor-thin strands about four inches long by a half-inch wide. Workers take these strands, dry them, mix them with resin and wax and lay them out into a big mat. The strands are oriented in different directions to give strength and stability to the board. For siding, a paper soaked with resin is laid over the top of the mat and then fed into a hot press, which compresses the material down to about one-half inch with an embossed wood grain texture applied to the outer surface. The panels are then cut into boards to make lap siding or into sheets to make panel siding.

Plywood is manufactured by first placing cut logs into a barker where they are rotated against a steel claw to strip the bark from the log. The logs are then sent to the lath where they are rotated as a steel blade peels continuous sheets of wood veneer. Plywood is composed of an odd number of thin sheets of wood veneer glued together with a resin. The wood sheets are oriented cross-grained and united under high pressure and temperature forming a panel. The thickness and orientation of the plies determines the performance of the panel. The resins and glues used in the manufacture of plywood may contain phenyl formaldyhide with filler and extenders of wheat flour, walnut shells, ground bark, wood flour, caustic soda (sodium hydroxide), and soda ash (sodium carbonate). Some glue formulations call for the use of animal blood. Plywood is used as sheathing, which is nailed to a buildings wood frame studs prior to the placement of exterior siding to increase rigidity, lateral stability, and heat-insulating properties of the exterior walls. Other uses of plywood include sub-flooring, countertops, panel doors, wall paneling, shelves, and the bus body and ship building industry.

Hardboard is made from softwood pulp, which is forced into sheets under heat and pressure. Hardboard may be tempered or un-tempered. The tempered variety is treated with oils and resins, which make it harder and more moisture-resistant. It is darker in color than the un-tempered type. It can be manufactured smooth or either front or back surfaced. Hardboard can come in the following forms: Standard- finished on one side, textured on the other, used in cabinets, drawer bottoms, concealed panels, enameled & pre-painted, often embossed with tile or plank patterns and used for wall or bath paneling, plastic-laminated- often used for sliding doors, and perforated- pegboard.

Particle board consists of compressed wood chips, slivers, sawdust, and shavings combined with an adhesive. These panels are dimensionally stable and non-warping due to their lack of grain. They are used as an underlayment for hardwood veneer, backing for laminated plastics, doors, cabinets, and as a finished wall surface to receive paint.

Wood-Plastic composites (WPC) are used to produce building materials which include decking, door and window frames, siding, exterior molding and roofing (figure 8). Manufactures claim that products produced with recycled wood /plastic lumber are more durable than preservative treated lumber. The market for WPC decking in the US has grown from 1% in the mid-1990's to a projected growth of 20% by 2010. Recycled wood/plastic composite lumber is one of the prime uses for recycled plastic garbage bags and waste wood fibers. Recycled WPC lumber typically consists of a 50/50 mix of wood fibers from recovered sawdust and high density polyethylene (HDPE) and poly-vinyl chloride (PVC). HDPE is the dominate resin in North America while PVC is more common in Europe. Wood and non-woody sources used in WPC include pallets, furniture waste, recycled wood floors, pine scrap, rice hull flour, paper waste, and pine flour fiber. As of 2004, at least 13 companies manufactured WPC products, each having different combinations of color, composition and external structure. Due to the variety of different WPC compositions it may be possible to trace the origin of the material to a specific company (figures 9-13).

In my experience teaching workshops in building materials analysis, I have found it instructive to prepare miniature walls and ceilings to simulate full scale structures. At the firing range the ‘mini-wall’ is mounted on a workbench with either ballistic vests or wet telephone books suspended behind the wall. Rounds are fired through walls using a handgun with hollow point ammunition. A log recording bullet direction through a variety of walls is prepared. Students are asked to examined the bullets and identify all building material traces and match the bullet to the ‘mini-walls’ including which direction the bullet may have traveled through the wall.

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