Science Of Engineering Tapes

written by Nirmal Raj Joshi | December 3, 2024

When one thinks about tapes, one might imagine a simple roll of something sticky. But dive into the aisles of a hardware store, and you'll find a world of tapes with unique powers—some strong enough to fix a broken car bumper, others designed to hold up in the rain, and some even with colours and textures that make them perfect for crafts.

When tape is applied, the adhesive flows slightly to fill in microscopic gaps and irregularities on the surface, creating a "mechanical interlock." This increases the contact area and strengthens the bond. Once the adhesive forms bonds with the surface molecules, the adhesive and cohesive forces work together to hold the tape in place. Depending on the formulation, the adhesive strength can be adjusted for temporary or permanent bonds, allowing tape to be used in applications from everyday repairs to specialized industrial uses.

Physics of bonding with tapes

The physics of tape is a fascinating blend of adhesion, cohesion, and surface energy, all of which allow it to stick to various surfaces and materials.

Adhesion and cohesion

At the molecular level, tapes rely on two types of forces: adhesion and cohesion. Adhesion is the force that causes the adhesive to stick to the surface of another material. When tape is pressed onto a surface, the adhesive flows slightly, allowing it to make contact with tiny grooves and imperfections on that surface. This contact is crucial for creating a strong bond, as it maximizes the area of interaction between the adhesive and the material. The adhesive layer then interacts with the surface through Van der Waals forces—weak electrostatic forces between molecules that can, collectively, provide substantial holding power.

Cohesion, on the other hand, is the force that keeps the adhesive molecules bonded to each other, maintaining the tape's structure. If cohesion is weak, the tape may peel or tear easily. This balance between adhesion to surfaces and cohesion within the adhesive is essential for effective bonding. Tapes are engineered to achieve this balance, ensuring they can be removed cleanly when necessary (like in painter's tape) or hold extremely well over time (like in duct tape).

Surface energy and pressure-sensitive adhesives

Another critical concept in tape physics is surface energy. Materials with high surface energy, such as glass or metal, are easier for adhesives to stick to, because they naturally attract the adhesive molecules more strongly. In contrast, low-energy surfaces like plastic or silicone are harder to bond with, which is why some specialty tapes are required for these materials.

Most tapes use pressure-sensitive adhesives (PSAs), which, as the name suggests, require only light pressure to bond with a surface. PSAs are soft enough to flow and make contact with a surface, and when pressed, they spread and form bonds with the material. This flow enables the tape to adhere without the need for heat, water, or other activators.

Anisotrpic tapes

Anisotropic tapes are specialized adhesives designed to exhibit different physical properties in different directions, typically in bonding, electrical conductivity, or thermal conductivity. Unlike isotropic tapes, which have uniform properties throughout, anisotropic tapes are engineered to selectively allow certain functions in specific directions. This property is particularly valuable in advanced electronics, where precise control of current, heat, or bonding is required. Creating anisotropic tape involves a structured process to develop directional properties for specific functions, like electrical or thermal conductivity, or vibration damping.

1. **Anisotropic Conductive Films (ACF)**: ACF tapes are commonly used in electronics manufacturing for connecting flexible circuits, flat-panel displays, and LCDs. These tapes are composed of conductive particles suspended within an adhesive. When pressure is applied, the particles align in one direction (usually vertically) to create electrical connections, while

remaining insulating in the lateral directions. This enables ACF tapes to form connections only where needed, reducing the risk of short circuits.

2. **Anisotropic Thermally Conductive Tapes**: In applications where heat dissipation is critical but electrical insulation must be maintained, anisotropic thermally conductive tapes are used. These tapes are designed to conduct heat in one direction (typically through the thickness of the tape) while preventing heat spread laterally. This focused heat dissipation is essential in managing hot spots in electronics such as processors and LEDs.
3. **Vibration-Damping Tapes**: In automotive and industrial applications, some anisotropic tapes are structured to provide vibration damping in specific directions. These tapes absorb and dissipate energy in the direction of applied force, minimizing vibration transmission through structures and improving stability and noise control.

Chemistry of tapes

The chemistry of tape adhesives varies, but common formulations include acrylic, rubber, and silicone-based adhesives.

1. Acrylic Adhesives: These adhesives are made from acrylic polymers, which provide strong bonding, resistance to temperature extremes, and durability against UV light. Acrylic adhesives are common in outdoor tapes and long-lasting applications.
2. Rubber Adhesives: These are based on natural or synthetic rubber and are widely used in tapes due to their flexibility, cost-effectiveness, and good bonding to a wide range of surfaces. Rubber adhesives are common in masking and electrical tapes, where a balance of strength and flexibility is needed.
3. Silicone Adhesives: Silicone-based adhesives are known for their exceptional resistance to temperature and chemicals, which makes them ideal for high-temperature or harsh environmental conditions. Silicone adhesives are used in tapes for applications involving electronics, medical equipment, and aerospace.

Difference between tapes and other glues

The primary difference between tapes and glues at the chemical level lies in their bonding mechanisms, application methods, and the types of adhesives used.

Application method

- Tapes use pressure-sensitive adhesives (PSAs) that are pre-applied to a backing material (like paper, cloth, or plastic). These adhesives don’t need a curing or drying process; they create bonds instantly when pressure is applied, allowing the tape to stick immediately. This convenience makes tapes useful for applications where a quick, non-permanent bond is needed.
- Glues, on the other hand, are typically liquids, gels, or pastes that must be applied directly to a surface and then undergo a curing or drying process. This curing process can involve chemical reactions (like with epoxy glues that harden when mixed) or evaporation (like with white glue). This process allows glue to form stronger, more permanent bonds by penetrating surface pores more deeply than tape.

Adhesive composition

- Tapes typically rely on pressure-sensitive adhesives made from polymers like acrylics, rubbers, or silicones. These materials are designed to have a tacky surface that sticks without the need for curing or chemical changes. The adhesive’s cohesive strength keeps it intact on the tape backing, while the adhesive properties ensure it bonds to surfaces under pressure.
- Glues are more varied in chemical composition. Depending on the type, they may contain polymers that polymerize (form long chains) or cross-link (bond across molecules) to harden. For example, epoxy glue contains two components that chemically react when mixed, creating a rigid, durable bond. Cyanoacrylate (super glue) undergoes a rapid polymerization process upon exposure to moisture in the air, forming a strong, irreversible bond. Other glues, like polyvinyl acetate (PVA) or polyurethane glues, rely on evaporation or chemical reactions to solidify.

Bonding mechanism

- Tapes depend primarily on surface adhesion for bonding. PSAs in tapes create bonds through Van der Waals forces, weak electrostatic interactions that allow them to adhere to surfaces without penetrating deeply. The tape’s backing helps distribute these forces over a large area, which is why tapes can be strong but are generally easier to remove.

- Glues use a mix of mechanical interlocking and chemical bonding. When glue is applied, it can flow into surface pores and, upon curing, form a mechanical lock with the material. In some cases, glues chemically react with the surface material, creating a bond at the molecular level, which often makes glued joints more permanent and resistant to separation than tape bonds.

Strength and durability

- Tapes are versatile and offer a quick, clean bond, but they generally do not have the durability or heat resistance of glues, especially in challenging conditions like high stress or extreme temperatures.
- Glues can form much stronger, more durable, and often waterproof bonds. Because they penetrate surfaces and chemically react (in many cases), glues create bonds that tapes cannot match in strength, making them suitable for structural or long-term applications.

Type of common tapes

Duct tape

Duct tape was invented by Vesta Stoudt, a factory worker and mother, during World War II. It was designed as a waterproof tape for the military to seal ammunition cases, repair equipment, and perform various field tasks. This original tape was strong, flexible, and had a cloth backing that made it easy to tear by hand. Due to its water resistance, soldiers began calling it “duck tape,” likely due to its resemblance to duck cloth (a durable cotton fabric) or its ability to “repel water like a duck.” After the war, the tape’s usefulness led to its adoption in the construction and HVAC industries. People discovered that the tape could seal ductwork effectively due to its strong adhesive and flexibility. It was around this time that it started being marketed as “duct tape” instead of “duck tape” because of its new application in sealing air ducts. Manufacturers eventually began producing silver-colored versions that blended well with metal ducts, further solidifying its association with ductwork.

Duct tape typically uses a rubber-based adhesive, which is known for its strong bonding strength, flexibility, and durability across various surfaces and conditions.

Uses: Known as the “fix-all” tape, duct tape is famous for its durability and water-resistant qualities. Originally developed to help seal ammunition cases during the war, duct tape today is commonly used to repair leaks, fix tears, and even create crafts. Its cloth-backed design gives it strength, while the rubber-based adhesive holds up even in rough conditions.

Masking tape

Masking tape is called “masking” tape because it was originally developed for use in “masking” areas—that is, covering or protecting parts of a surface that should not be painted or finished. The term “masking” in this context refers to blocking off a section to create clean lines or boundaries in processes like painting, varnishing, and finishing work. Masking tape was invented in 1925 by Richard Drew, an engineer at 3M. At the time, car manufacturers faced a problem during the two-tone car painting trend: painters needed a tape that could protect parts of the car while the rest was painted, without peeling off the paint beneath it. Drew created a tape with a low-tack adhesive that was sticky enough to adhere temporarily but gentle enough to remove without damaging or lifting the paint underneath.

Masking tape typically uses a rubber-based adhesive with differnet formulation than duct tape. This type of adhesive has moderate stickiness, which allows the tape to adhere well to surfaces temporarily while still being easy to remove without leaving residue. Rubber-based adhesives work well for short-term applications and stick effectively to a variety of surfaces, including walls, wood, and glass.

The purpose of masking tape is to mask off or shield parts of a surface, keeping them untouched by paint, varnish, or other substances. This “masking” capability makes it essential for achieving precise edges and clean lines, especially in painting and decoration projects. Masking tape has a paper backing that is easy to tear and a special adhesive that leaves minimal residue, allowing for easy removal after the task is completed.

Uses: Masking tape is a favorite among painters and crafters. Its low-tack adhesive allows it to peel off without leaving residue, making it perfect for protecting areas during painting or creating clean edges. While not as strong as duct tape, it’s gentle enough to be used on walls, paper, and other delicate surfaces.

Electrical tape

Electrical tape is specifically designed to insulate electrical wires and other conductive materials, protecting them from short circuits and other electrical hazards. The name reflects its primary purpose in electrical insulation and safety applications. Electrical tape was

originally developed in the 1940s by 3M. At that time, electricians commonly used friction tape—a rubber-based adhesive with a rough, cloth backing. While friction tape provided insulation, it was bulky and difficult to work with. To address these issues, 3M introduced a vinyl-based tape that was flexible, easy to handle, and capable of providing a more secure and durable insulation.

The key feature of this vinyl electrical tape is its non-conductive, heat-resistant, and flame-retardant properties, which make it ideal for electrical applications. Vinyl tape also has low elasticity, allowing it to stretch and conform to irregular shapes, making it especially useful for wrapping around wires and connections.

Uses: Electrical tape is essential in electrical work because it's non-conductive and can insulate wires safely. Typically made from vinyl, this tape stretches to wrap around wiring, protecting it from moisture and wear. Electricians rely on it for safety, but it's also useful in home repairs involving small electronic fixes.

Friction tape

Friction tape was traditionally used for insulating electrical wires and other components, particularly in the early-to-mid 20th century. It is composed of a rubber-based adhesive that is applied to a cloth or fabric backing, which gives it flexibility and durability. The tape gets its name from the fact that it was originally used to wrap around parts that were subject to friction, such as on rotating machinery or electrical connections, as well as for insulation purposes.

Friction tape was widely used in automotive, aviation, and electrical industries for wiring insulation, particularly for motor windings and transformers, where wires needed to be insulated and protected from heat and friction. It was also used to wrap electrical components to prevent shorts and to provide a barrier against environmental elements like moisture, dirt, or chemicals.

Although it has largely been replaced by more modern materials like PVC electrical tape, friction tape still holds a historical significance in the development of electrical insulation materials. Its unique combination of flexibility, insulation, and durability made it essential in many early electrical and mechanical applications.

Packing tape

Packing tape are made of a thin plastic film, typically polypropylene, with a strong adhesive layer. It's clear or translucent, lightweight, and flexible. It was invented by Henry Ford introduced the concept of cellulose tape in the 1920s, which later evolved into modern packing tape. Packing tape got its name because it was specifically designed for the purpose of sealing and securing packages, boxes, and other parcels. I The tape's adhesive strength and flexibility make it ideal for keeping boxes closed during handling and transit.

Packing tape typically uses one of two types of adhesives: acrylic-based adhesive or hot melt adhesive, each chosen for its strong, durable bond and suitability for long-term packaging.

Uses: Known for its clear, strong hold, packing tape is widely used for sealing cardboard boxes and shipping packages. Its robust adhesive is designed to secure heavy loads during transportation, making it the go-to for mailing and moving.

Double-Sided tape

Double sided tape was invented by 3M in the mid-20th century.

Uses: Double-sided tape is unique because it has adhesive on both sides, making it perfect for projects where the tape shouldn't show. From mounting photos to wall hangings, this tape offers a clean look while still holding items securely in place.

Gaffer tape

Gaffer tape is a heavy-duty, fabric-based adhesive tape similar to duct tape but specifically designed for the film, theater, photography, and live production industries. It is known for its strength, flexibility, and unique adhesive properties. It uses a non-permanent rubber-based adhesive that provides a strong hold but is designed to be removable without leaving residue. Unlike duct tape, it won't damage surfaces or leave a sticky residue upon removal. It was invented by Ross Lowell in the 1950s

Uses: Popular in the film and theater industries, gaffer tape is known for its ability to secure lighting and cables without leaving residue when removed. It's durable but doesn't damage surfaces, which makes it invaluable on sets where equipment needs to be easily movable.

Painter's tape

Painter's tape is a specifically designed for painting projects to create clean, precise lines and protect surfaces from paint. It's widely used by both professionals and DIYers. It was invented by 3M in the 1980s. Although similar to masking tape, painter's tape is typically

more advanced than regular masking tape, offering better clean removal, UV resistance, and less risk of bleeding paint under the tape. Masking tape can be used in painting, but painter's tape is generally preferred for professional, residue-free results.

Uses: Designed for painting projects, painter's tape is easy to apply and even easier to remove. It prevents paint bleed, allowing for clean, sharp edges on walls and art projects. Its adhesive is specially formulated to not damage surfaces.

Scotch tape

Scotch tape is a type of transparent adhesive tape created by 3M, known for its versatility and widespread use in household, office, and craft applications. Originally introduced in the 1930s, Scotch tape has become one of the most recognized brands of clear tape. Scotch tape typically has a backing made of a clear plastic film, such as cellulose acetate or polypropylene, which gives it its transparency and durability. The adhesive used in Scotch tape is generally an acrylic-based adhesive, which provides a strong hold on paper and other smooth surfaces without being overly aggressive. It's pressure-sensitive, meaning it adheres better when pressed down firmly.

Compared to other tapes like packing tape or duct tape, Scotch tape is relatively light-duty. It is ideal for paper and light bonding but lacks the strength for heavy-duty repairs or packaging.

Uses: Probably the most well-known tape, Scotch tape is a clear adhesive tape that's used for general purposes, from wrapping presents to quick fixes around the house. It's less durable than other tapes but ideal for light-duty tasks where visibility is important.

Foam tape

Foam tape is a double-sided adhesive tape made from a foam material, typically used for mounting, sealing, and cushioning applications. Its flexibility and ability to conform to irregular surfaces make it valuable in a wide range of industries, including automotive, construction, and household applications. Foam tape has a thick, flexible foam core, which can be made from materials like polyethylene, polyurethane, or acrylic. This core provides cushioning and can absorb vibrations. This tape often uses a strong acrylic or rubber adhesive on one or both sides, offering a firm hold on a variety of surfaces, including metal, plastic, and glass.

Unlike traditional adhesive tapes, foam tape is thicker and provides a cushioning effect, ideal for heavier or uneven surfaces. Its double-sided adhesive nature and strong, durable hold make it more versatile than single-sided tapes for specific applications.

Uses: Foam tape is unique for its thickness, providing a cushion between surfaces. It's often used in automotive and construction applications to absorb vibrations or seal gaps, making it an ideal choice for soundproofing or sealing windows and doors. It is frequently used to mount objects like mirrors, signs, and wall decorations, as it can support moderate weight without the need for nails or screws. In construction and automotive applications, it is used to seal windows, doors, and gaps to prevent drafts, moisture, and dust. Sometimes it is used for shock absorption.

Heat-Resistant Tape

Unlike standard adhesive tapes, heat-resistant tape is specifically engineered to endure high temperatures and maintain functionality, whereas regular tapes can melt, lose adhesion, or become ineffective under heat. Its specialty lies in combining durability with thermal resistance. Heat-resistant tape is made from materials that can endure high temperatures, such as polyimide (Kapton), teflon (PTFE) and silicone .

Typically a silicone-based adhesive is used due to its ability to remain stable and effective under high temperatures, often up to 260°C (500°F) or more.

Uses: Designed to withstand high temperatures, this tape is used in environments with extreme heat, like automotive, aerospace, and electronics. Its materials resist melting, making it essential for high-temperature applications.