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PROTECTIVE RUBBER LININGS

Rubber as a Protective Lining

Since 1893 when Charles Goodyear discovered the process called vulcanization whereby a soft amorphous mass of natural rubber cross linked into a resilient elastomeric material with excellent elongation, modulus, and tensile strength has rubber been used as a material in manufacturing. While the uses of rubber are many and varied, including the manufacture of vehicle tires, roofing materials, latex, surgical gloves, erasers, pond liners, and many other products, it is the use of rubber in for corrosion and abrasion protection that is covered herein. Rubber, in the form of prefabricated sheets, has been successfully used as a lining material in storage tanks, water boxes condensers, Flue Gas Desulfurization (FGD) units, chemical scrubbers, pipelines, mixers, valves, and pumps. Because of superior impact abrasion and chemical resistance, rubber linings in the range of 1/8" (3mm) -1/2" (12mm) thick can often out perform conventional liquid applied linings by many years. In many installations, rubber linings have a life expectancy of 25-30 years.

Commercial Lining Products

Rubber lining products are manufactured in a broad range of compositions and configurations tailored to meet specific requirements for resistance to chemicals, abrasion, impact, and temperature. Typically, rubber sheet us supplied at a thickness from 1/8" (3mm) -1/2" (12mm). Most industrial lining work utilizes 1/4"(6mm) sheet stock and standard roll widths are 48"(1.21m). Most rubber manufacturers extrude, calendar the compound in sheets to a desired thickness by laminating thin sheets on the calendar. The sheets are then laminated together to form the finalized sheet, a process called calendaring. Sheets laminated made by calendaring by other sheets have the advantage that a tear or weak spot in one calendar layer can be covered by other layers, and thus rubber properties and thickness are uniform, and pinholes through the lining is minimal and virtually impossible. Also calendaring allows rubber sheets of different types and properties to be laminated into a single ply sheet that may have improved over plied sheets of different of all the same type of rubber.

Rubber Lining Application

Once the proper rubber for a given application is chosen, it is applied in five basic steps:

1. Prepare the surface for rubber application, usually by solvent cleaning, and blast cleaning to remove all contamination, and to roughen the surface for better adhesion.
2. Apply the adhesive system to the surface to be lined. The adhesive may be a single coat or a multi coat system.
3. Apply cut to fit rubber sheets to the surface using rollers and stitchers to press out air pockets and to press the sheet into the adhesive.
4. Cure, or vulcanize the rubber lining by steam in an autoclave, exhaust steam, or by chemical application to the rubber surface.
5. Inspect visually for bubbles or blisters, and for pinholes using a high voltage holiday spark tester.

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Types of Rubber
Rubbers can be categorized as a natural rubbers and synthetic rubbers. The natural rubbers are manufactured from a tree sap from the Far East. Synthetic rubbers were developed on a commercial scale by researchers of the War Production Board in the United States in the early 1940's as a substitute for the natural rubber sources that were under controls of the axis forces
(notably Japan) during World War 2.

Natural Rubber (NR)
The precursors of rubber and rubber like compounds are examples of some of the earliest materials that civilized man learned to extract and process from plant sources. Many plants produce a milky sap that can be harvested, coagulated, and converted to a crude elastomer. The earliest natural rubber was named "catouchouc". It was derived from an East Indian word meaning "weeping tree". The term survives today and is used to designate a family of raw, plant derived, macromolecular compounds that can be converted to natural rubber. Modern analytic analysis has identified these materials as variations of natural occurring polyisoprene. Latex producing plants, of which there are hundreds, are predominately found in tropical climates. The plantation economies of Malaysia, Indonesia, and Thailand account for nearly 90% of the global production of raw natural rubber.

Natural rubbers are compounded in three forms: soft, semi-hard, and hard. Soft natural rubbers have excellent physical properties, like tensile strength, abrasion resistance, and elongation. Soft natural rubbers have good resistance to most inorganic chemicals, with the exception of strong oxidizing agents to a temperature of 140^{0}F (60^{0}C). They are flexible and will expand and contract with thermal variations of the metal substrate.

Semi Hard and hard natural rubbers exhibit better chemical and heat resistance than soft natural rubber. The linings see wide application where exposure to organic acids, inorganic acids, and chlorine gas is anticipated. The linings exhibit heat resistance to permeability, but have less flexibility. Ebonite, which is the hardest of all the natural rubbers, is a graphite filled material resembling a thermo set plastic with a very high cross linked density. The hard rubbers can be machined after vulcanization to make acid resistant seals, valves and pump bodies. Hard Rubbers will resist extreme corrosive exposure from wet and dry chlorine gas. They offer chemical resistance to a wide range of chemicals at a level between 150-200^{0}F (65.55-93.33^{0}C).

Soft Natural Rubbers:

Strengths	Weaknesses
• Excellent abrasion resistance • Good Resistance to many acids and alkalies • Remains flexible to very low temperatures • Good resistance to mechanical and thermal shock • Lower in price than most other linings • Easy to install and repair	• Poor sunlight, oxidation and ozone resistance • Special ingredients can be added to improve properties • Poor resistance to strong oxidizing acids such as nitric and chromic • Poor resistance to temperatures above 160^{0}F (71.1^{0}C) • Special compounding can raise the temperature limits • No resistance to oil or hydrocarbons

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Common Uses:
• Hydrochloric acid processing, storage and transportation equipment • Hydrofluoric acid storage and transportation when the concentration is greater than 50% • High abrasion areas in mining, mineral, and aggregate processing such as slurry pipes, screen decks, chutes and hoppers.

Semi Hard Rubbers

Strengths	Weaknesses
• Good Resistance to Chemicals • Good heat resistance up to 212F • Low water absorption • Low permeation rate • Moderate cost	• Poor abrasion resistance • No oil resistance • Poor low temperatures
Common Uses:	
• Wet Chlorine services • High temperature services	

Neoprene / Chloroprene Rubber (CR)

Chloroprene (2-chlorobtadiene) rubber was initially compounded in 1939 as Neoprene. CR is a polar rubber because it contains a ratio of chlorine atoms to carbon atoms of 4:1. Chlorine content also imparts better flame resistance, weather ability, and ozone resistance experienced with diene rubbers. The swelling resistance of CR to mineral, vegetable, and animal oils is also better than the non polar diene-based rubbers. CR has good resistance to paraffinic and naphthenic oils of high molecular weight, but swell extensively in aromatic oils of low molecular weight. CR is degraded (swells) by contact with motor fuels, but its resistance can be improved though higher levels of filler loading and degrees of crosslinking. In lining service, with general chemical exposure, CR has heat resistance to 150^{0}F (65.55^{0}C) with strong acids (sulphuric acid) and 200^{0}F (93.33^0) with strong bases (sodium hydroxide)

Neoprene / Chloroprene Rubber (CR)

Strengths	Weaknesses
• Excellent oxidation, UV, and ozone resistance • Moderate oil resistance • Fire resistance • Good abrasion resistance • Good low temperature properties and high temperatures up to 212^{0}F (100^{0}C)	• High material costs • Could be difficult to install • Hot tables are required to preshrink the lining
Common Uses:	
• Sea water piping • Tumbling barrels • Services that contain small amounts of oil or other hydrocarbons • Caustic storage tanks	

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Butyl Rubber (IIR)
Butyl rubber, a blend of isoprene and isobutylene copolymers, is along with Nitrile and neoprene, one of the oldest synthetic rubber lining products. The large scale production of butyl rubber began in 1943. Typically, the rubber exhibits a high level of heat and heat aging resistance to 225⁰F (107.22⁰C). It has good resistance to a broad array of general chemical solutions at 180-200⁰F (82.22-93.33⁰C). Because butyl rubber is non-polar, it will swell upon contact with lubricating oils and fuels.

Butyl Rubber

Strengths	Weaknesses
• Excellent oxidation and ozone resistance • Very low permeation rate • Low water absorption • Good resistance to elevated temperatures up to 260⁰F (127⁰C) (Bromobutyl) • Good resistance to a wide variety of chemicals	• No resistance to oils or hydrocarbons • Costs more than natural rubbers
Common Uses:	
Blended Chlorobutyl / Bromobutyl • Phosphoric acid production, storage, and transportation • Ferric Chloride storage and transportation • FGD scrubber towers, piping and limestone slurry tanks • Sulphuric acid storage – up to 50% concentration • Open top storage tanks that require good weather resistance	
Unblended Chlorobutyl • Bleach (Sodium Hypochlorite) storage / transportation • Hydrofluoric Acid (above 50% concentration) storage / transportation	

Ethylene-Propylene Rubber (EPDM)
Ethylene-Propylene Rubber (EPDM) is manufactured by the copolymerization of ethylene and propylene with the addition of a diene monomer to create an unsaturated rubber terpolymer. Sulfur added during vulcanization completes the cross-linking that produces a usable rubber product. EPDM rubbers exhibit excellent heat, aging, and weathering resistance. The rubber exhibits excellent resistance to chemicals such as: acids, alkalies, acetone, alcohol, hydraulic fluids, and steam. Service temperatures in the range of 180-200⁰F (82.22-93.33⁰C are possible with EPDM. However, concentrated and/or strongly oxidizing acids may attack EPDM. The use in acid service is strongly dependent on operating temperature and acid concentration. Since EPDM is a non-polar material, contact with aromatic and chlorinated hydrocarbons will cause swelling.

Nitrile Rubber (NBR)
Nitrile rubber (NBR) is a product formed by the copolymerization of acrylo nitrile and butadiene. Many grades of NBR are available in which the acrylo nitrile content varies from 18 to 51% by weight. The addition of acrylo nitrile enhances swelling resistance and impermeability. NBR is a polar-type rubber used where exposure to aliphatic hydrocarbons is a service condition. NBR exhibits good resistance to swelling when immersed in liquids that are non – or weakly polar, such as gasoline, grease, mineral oil, and animal or vegetable fats and oils. Polar and aromatic solvents attack NBR. It should not be used with such aromatic solvents as: benzene, toluene, or xylene. NBR is less permeable to gases than natural rubber or SBR rubber. However, it exhibits significantly improved heat and aging resistance to a level of 200⁰F (93.33⁰C).

Styrene-Butadiene Rubber (SBR)
Styrene-Butadiene Rubber (SBR) is a product formed by the copolymerization of styrene and butadiene. Many grades of NBR are available in which the styrene content varies from 23 to 40% by weight. SBR has better heat resistance, 170^{0}F (76.66^{0}C) than natural rubber. SBR has superior impact and abrasion-resistant properties. Its principal use is in troughs, chutes, hoppers and ball mills to protect metallic substrates from mechanical damage. However, SBR also has good resistance to water and weak chemical solutions. As a non-polar rubber, contact with aliphatic, aromatic, and chlorinated hydrocarbons will cause swelling.

VULCANIZATION

Vulcanization (curing), a critical stage of processing, is necessary to enhance the performance properties of raw compounded rubber through cross-linking of its molecular structure. Cross-linking (copolymerization) is accomplished through a reaction with accelerators like organic peroxides or sulphur that are mixed into the raw rubber base. The cross linking process is called "vulcanization (to over-vulcanization on prolonged heating). For this reason, many synthetic rubber formulations display improved resistance to thermal exposure and heat aging. The four basic methods for vulcanizing, or curing rubber linings are autoclave, internal steam, atmospheric steam, and ambient (chemical cure).

AUTOCLAVE CURE
This method involves placing the object(s) to be covered or lined with rubber inside a pressure vessel called an autoclave. A controlled and continuous flow of steam from a boiler is introduced into the vessel. At the start of the process, air is purged from the autoclave. The temperature and pressure is carefully monitored. Because an autoclave offers the best form of control over the vulcanization process, it offers the greatest potential for producing uniform and high-quality products. However, to achieve these goals, it is recommended that the autoclave be equipped with precise controls for air pressure and steam. Variations in steam pressure and temperature will lead to undesirable anomalies in the cured rubber. Once started, an autoclave cure should never be interrupted. Prompt cool-down at the termination of cure is also important. Proper cool-down of the autoclave will prevent post-curing and preclude the possibility of blistering and cracking hard rubbers. While autoclaves can offer precise management of the vulcanization process, they are size-limited. Large tanks, water boxes, and other process equipment cannot fit inside. Rubber applied to these units must be vulcanized by other means.

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INTERNAL STEAM CURE
Internal steam pressure vulcanization is used on vessels that are designed to operate at elevated pressures and are too large to be placed in an autoclave. By this method, units can be installed and the linings cured in place. Internal curing should be accompanied by the installation of drains and traps to collect steam condensate. Recording thermometers and pressure gauges installed near the bottom of the vessel are used to monitor the process. Blind flanges should be installed at other openings. Bottom outlets should initially be left open to purge the vessel of air. Boiler capacity should be sufficient to raise the temperature from ambient to cure in a relatively short period. Long runs of uninsulated pipe between the boiler and lined vessel should be avoided. Once started, the vulcanization process should not be interrupted. Once the endpoint of the cure is reached, the vessel is cooled down by the introduction of air. Any steam-induced curing cycle should include an appropriate vacuum-break device to prevent a vacuum collapse of the vessel.

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ATMOSPHERIC STEAM CURE

Atmospheric steam is normal used for field vessels that have open tops or bottoms, or cannot withstand elevated pressures. With the case of open tanks, suitable temperature-resistant, steam-tight covers must be fabricated for all openings. Steam is introduced through an insulated steam line through a piping connection or opening in the top of the vessel. Provisions must be made to drain all condensate that collects at the tank bottom. Other outlets should be closed with blind flanges drawn up to within 1/32" of the flange rubber. Vulcanization at atmospheric pressure will allow entrapped air under linings to form blisters. Some procedures call for a pre-cure steaming period of one hour, followed by an internal inspection of the tank to located and repair spontaneous blisters. In this method, entrapped air is removed by deflating the blister with a hypodermic needle and applying a small patch of uncured rubber. The vulcanization process then proceeds to completion.

AMBIENT (CHEMICAL) CURE

Rubber is cured at ambient temperatures when heat cannot be applied to surfaces to achieve vulcanization. The method is most commonly used when patches must be applied to vulcanized rubber surfaces. A chemical cure may also be used when surfaces like flanges will be shielded from steam exposure. These methods expose the raw rubber to a sulphur-bearing chemical for a sufficient period to complete cure. The chemicals include carbon disulfide and sulphur dichloride. They are used as either a solution applied to the rubber surface or vapour form. Vulcanization is accomplished in periods of up to one week. If the vessel will operate at temperatures of up to 150°F, the chemical cure can be shortened.

SELF VULCANIZED (COLD BOND)

In the case of some on-site rubber linings where other curing methods are impractical, self vulcanized rubber sheets have been developed. The rubber in these sheets, specific soft rubber mixtures commonly used with a partial cured polychloroprene bottom layer for greater adhesion strength. These linings are ideal for chemical and high abrasion patch repair work. Self-vulcanized sheets can also be stored indefinitely, and installed as fully vulcanized linings. As such, they will be immediately resistant to the operational environment.

INSPECTING RUBBER LINING WORK

Inspection before Lining

Surfaces to be covered with rubber should be cleaned by abrasive blasting to achieve a cleanliness equivalent to Steel Structures Painting Council Specification SSPC SP-5, "White Metal Blast Cleaning". The cleaned surfaced should have a minimum surface profile of 2 mils. The surfaces to be coated should be free of all oil, grease, mill scale, rust, corrosion products, oxides or other foreign matter. Primer should be applied immediately after cleaning and before any visible surface oxidation has occurred. Precautions must also be taken to avoid condensation when applying primers and cements to metallic surfaces. No operations should be conducted when the metal temperature is within 5°F (-15°C) of the dew point.

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Inspection During Lining Operations
The installation of a rubber lining system involves a series of steps. Each one requires surveillance to ensure that the specification representing the manufacturer's recommendations is being followed. Liquid primers-used to prepare the metal surface, and liquid cements-to create an adhesive bond at the metal-rubber interface, and rubber-rubber interfaces, are generally applied by hand brush. Different rubber systems require different primers and cements. Separate brushes and rollers should be maintained for each type of primer and cement used in the installation. In this work, the sequence of application, drying time and selection of the mating surfaces are critical to the success of the work. The manufacturer's recommendations should be diligently enforced.

Joints are usually necessary in lining work, because many sheet rubber materials are supplied in widths up to only 48". Four methods of construction are typically used to join rubber panels with the selection determined by the type of elastomeric used.[9]

Butt Joint – A joint where the two rubber panels are laid edge to edge without any tapered mating surface. Butt joints are usually covered with an additional cap strip.

Lap Joint – A joint where one rubber panel overlays the next. A minimum overlap of 2" (5.08cm) is recommended at the joint.

Skive Joint – A joint where one rubber panel is butted against the next piece. Skives should be cut at a 45° angle between abutting pieces.

Closed Skive Joint – A butt joint where a reverse 45° angle cut is made between the abutting rubber panels. The reverse skive is the recommended joint for all rubber panels. It is required whenever multi-layer rubber sheet containing a tie gum is used. The reverse cut allows the installer to stitch down the cut edge so that the tie gum is protected from chemical attack.

Stitching is a method of joining two pieces of uncured rubber. It utilizes a hand-held tool called a stitching roller. The tool is a narrow wheel with a serrated edge that applies a continuous line of localized compression points to drive the rubber panel into the adhesive layer.

Joint construction should comply with both the specification and the manufacturer's recommendations for the rubber product used in the installation.

After the rubber sheet is applied to the cured cement, it must be rolled tightly against the metal to remove any trapped air and ensure intimate contact across the metal-rubber joint. Joints should be examined to verify that the seams are straight and all edges are stitched down tightly.

Inspection before cure

Immediately following the application of the rubber to the metallic surfaces. The lining should receive an inspection to ensure that the following parameters have been met:

The lining should be checked to assure that the physical dimensions of protected surfaces and the thickness of linings comply with the requirements of the specification. Modifications are more easily made before the system has been cured (vulcanized). Unacceptable areas should be marked with chalk.

Prior to vulcanization, all lined surfaces should be inspected for blisters, wrinkles, pulls, lifted edges (bond failures), or surface defects. All splices (joints) in the lining system should be inspected for integrity and uniformity. Whenever layered rubber stock is used, stitched-down splices are necessary to protect the tie gum.

Air trapped under the rubber sheet should be located and removed. Air bubbles can be located by lighting the surface from an oblique angle and looking for shadows cast by the high spots. The air can be released with a hypodermic needle and the site stitched-down or patched. This step is especially important when atmospheric cures are used with no applied pressure to force out air or flatten the lining.

The lining should be examined for pinholes, punctures, and cuts with a high-voltage spark tester. Both the Rubber Manufacturers Association (RMA) and the American Society for Testing and Materials (ASTM) have written standards for the spark testing of elastomeric sheet linings.10 High frequency, AC-type spark testers, capable of producing sufficient voltages to achieve proper calibration should be used. Voltages should comply with those recommended by the rubber manufacturer and will vary with thickness and rubber type. The inspection voltage range for most rubbers is between 10,000 and 15,000 volts. Lined tanks should be purged of all volatile vapors and solvents before high voltage spark testing is applied.

Post Cure Inspection

Following completion of the vulcanization process, the rubber surfaces should be inspected for signs of obvious imperfections. These may take the form of loose splices, trapped air blisters and breaks in the lining.

The hardness of the cured rubber should be checked with an appropriate durometer in accordance with a standard test procedure.11 Durometer (indentation hardness) measurements should cover the entire rubber surface. One reading per 100 square feet of surface should be taken and recorded. The measurements should fall within the tolerances recommended by the manufacturer’s specifications for the vulcanized product. Areas of the lining that fall below the manufacturer’s tolerances should be isolated and cured through localized exposure to additional hot air or steam.

The rubber surfaces should again be inspected using a high voltage spark tester that is calibrated and adjusted in accordance with the rubber manufacturer’s guidelines. Pinholes and flaws located by spark testing should be repaired in accordance with specified procedures and vulcanized through exposure to hot air, steam or infrared lamps. If cold patches are utilized, they should receive an appropriate chemically induced cure.

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Post-Installation Inspection of Rubber Linings
Periodic inspections of rubber linings are usually conducted to determine if there are any flaws or lining anomalies that have developed during the course of operations within vessels, tanks, pipelines and other lined equipment. Among the areas that can be investigated are:

Appearance – A visual inspection can be conducted to locate such lining anomalies as blisters, bubbles, open or loose seams and patches, pinholes or discoloration. In steel tanks, breaks in the lining are often associated with corrosion products that cause localized disbondment and staining.

Hardness – is measured by using either the Shore "A" or Shore "D" Durometer on the cured (vulcanized) rubber system. Durometer measurements can be made to determine if there has been a significant change from the rubber hardness after vulcanization and before vessel operation. These could include hardening form overheating or softening form exposure to aggressive chemical.

Electrical Integrity - A high voltage inspection can be conducted of the rubber lined surface. However, such an inspection should only be made with the concurrence of the rubber manufacturer, using recommended voltage levels. Some rubber linings that have been in immersion or chemical service will undergo resistivity changes from absorbed moisture and/or chemicals. These changes wither preclude the use of high voltage inspection or require reduced voltages.

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