A Review on theories of Adhesive: Types and Applications

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***Abstract*-The phenomena of holding two materials together for a long time through specific interfaces is known as bioadhesion. These concepts are used in the research and production of high-performance adhesive materials, which have found numerous home and industrial applications. Natural rubber was the first pressure-sensitive adhesive to be employed in the formulation of bandage materials. Synthetic rubber followed second, The developments in the production of elastic sealants made from synthetic and natural materials are analyzed critically. Different natural based adhesives are described to understanding the mechanism toward the formulation. Different type of adhesives mentioned to described the different material used for the preparation. Marketed formulations gives idea about ingredient. According to different theory in their paper mention the van-der wall forces, electrostatic forces, acid-base interaction etc. The evaluation test included are pH, peel strength, viscocity, FTIR, Patch test, spreadability etc. Application mention by depending upon the uses along with advantages and disadvantages. The conclusion is that adhesives have been used in industry for decades; but, the environmental influence of adhesives has not been investigated up until recently. Therefore, this study help to emphasized on the new or combination adhesives that necessity allow obtaining environmentally safe and high-quality adhesives**

***Keywords*- Adhesion, Adhesive, Natural rubber, synthetic rubber**

I. INTRODUCTION

Substances that may permanently bond to surfaces using an adhesive method are known as adhesives. The phenomena of holding two materials together for a long time through specific interfaces is known as bioadhesion. These concepts are used in the research and production of high-performance adhesive materials, which have found numerous home and industrial applications[1]. Bioadhesion refers to the adhesion qualities that bind two surfaces together. Shoes, cars, boxes, furniture, non-woven fabrics, and a wide range of other products all depend on adhesives. The use of adhesives in the manufacture of airplane was originally encouraged by the aerospace industry[2].

Adhesives have numerous uses in the medical, dental, and pharmaceutical fields because they are employed in the healthcare industry. Modern adhesives come in many forms and are utilised in dentistry, medicine, and the manufacturing of thousands of medical devices[2].

The term "bioadhesive" refers to an adhesive that interacts with biological tissue. A compound's ability to attach to a biological substrate for an extended period of time is known as bioadhesion[2]. In addition to hydrogen bonding, capillary forces, van der Waals forces, static electric forces, and covalent bonds, the principal adhesion mechanisms of these tissue adhesives are molecular bonding, mechanical coupling, and thermodynamic adhesion[3]. Based on the conditions of their use, bioadhesives can be divided into internal and exterior types. External bioadhesives are typically used in topical treatments including epidermal grafting and wound closure. Internal bioadhesives are mostly employed in intracorporal circumstances where they come into direct touch with internal environment, including tissues, organs, and body fluids, such as chronic organ leak repair and bleeding complications reduction[4].

Adhesive is dependent on adhesion's mechanical and chemical properties. The primary and secondary chemical bonding interface is where chemical bonding mechanisms are basically found[5].

II. DIFFERENT TYPES OF ADHESIVES

Pressure Sensitive adhesive[FSA]-When you slightly apply force on pressure-sensitive adhesives, they can adhere to the surface of a material with easily. They are composed of rubber, acrylic, and silicone. When using

a pressure-sensitive glue, you can easily make the adhesive stick by exerting a little force; you don't need water or heat for this to happen. FSAs are usually applied in cartons and floor lamination.

Polymer Based adhesive[PBA]-PBAs are used in a variety of materials, such as resins, epoxies, urethanes, and methacrylates. These products are the most popular because they are the strongest, most adaptable, and most resistant to environmental factors. PBAs are typically used to seal fuel tanks, pipes, and many other chemical equipment as well as oil tanks.

Hot Melt adhesives-, also known to as hot glue, are supplied as cylindrical sticks that are applied with a hot glue gun. The heating element that comes with the pistol dissolves the plastic glue while forcing it out of the nozzle .Hot melt adhesives can be used to connect metals, glass, textiles, and cardboard, but they work best for woodworking applications.

Electrically Conductive adhesives-The connection of electrical components is the main use for electrically conductive adhesives. They are extremely long-lasting, biocompatible, and durable. Electrodes on a heart monitor are a classic example of a medical sensor that is compatible with electrically conductive adhesives.

Casein adhesives-A special kind glue made from milk protein is called casein. Since the Medieval, one of the strongest and oldest glues has been used to construct and join picture frames. Casein is now utilised in the manufacture of furniture, bottles, musical instruments, and more.

Solvent Based adhesive[SBA]-An adhesive polymer solution is made by combining an adhesive substance with a suitable solution to produce SBAs. Solvent-based adhesives are useful in places that require strong resistance to temperature, water, and extreme environmental conditions. They are available in solution form.

Water Based adhesive-Evaporation works as the cure for water-based adhesives. They are mostly used for cosmetic reasons and have a texture similar to cement. They continue to perform best during bottling and packing, nevertheless.

III. DIFFERENT AGENT USED FOR ADHESION

Natural rubber was the first pressure-sensitive adhesive to be employed in the formulation of bandage materials. Synthetic rubber followed second, and today's importance of polyacrylic acid ester-based adhesives has increased. To cover and protect wounds, to seal the skin borders of a wound, or to support an injured area of the body, a variety of medical adhesive tapes, dressings, and devices are utilized . The term "bioadhesive" refers to an adhesive that interacts with biological tissue.. Van der Waals forces, hydrogen bondings disulfide bridges, hydration forces, hydrophobic contacts, steric forces, and covalent bonds are some of the forces that explain bioadhesion and are explained by theories[6]. Polymers can be either synthetic or natural, or both, for forming sealants. [7] To stop air and liquid leakages during and after surgeries, sealants have shown possibilities as a replacement for staples and sutures. The successful application of these materials in clinical practise is largely due to their physical characteristics and adhesion strength to seal the wound region without affecting tissue movement and function. The developments in the production of elastic sealants made from synthetic and natural materials are analysed critically and their limitations are highlighted in this contribution.

Natural Agent:

- Animal Sourcce : Albumin, Casein, Shellac
- Vegetable Source : Gum Arabic, Tragacanth ,Colophony
- Oil and Waxes : Carnauba wax and different oils
- Protein : Soyabean
- Carbohydrate : Starch and Dextrin
- Mineral : Paraffin and Amber

Synthetic agent:

- Synthetic Rubber: Polyisoprene, Polybutadiene, polysulphide, polyethylene, polysulfide,
- Reclaimed Rubber
- Neoprene Rubber
- Nitrile Rubber
- Dendrimer

IV. DIFFERENT NATURAL BASED ADHESIVES:

Protein-based bioadhesives are more biocompatible. They have benefits like simplicity of use, quicker recuperation, stronger seal, and efficient sealing. Bioadhesives are also used in a wide range of industries, including tissue engineering, regeneration, and controlled, site-specific drug delivery. The majority of the biological sticky classes are proteins. [20].

adhesive based on fibrin: The majority of tissue adhesives on the market are fibrin sealants, which are likewise biocompatible and biodegradable. Nowadays, fibrin sealants are employed in a variety of surgical specialties, including dental surgery, plastic and reconstructive surgery, cardiovascular surgery, and thoracic surgery. Applying fibrin sealants expedites hemostasis, reduces blood loss, and eases issues, all of which are advantageous for the success of surgery. [8]

Collagen Based adhesive: The most prevalent structural protein in connective tissues of animals is collagen. Multiple biological applications have seen thorough research into collagen-based biomaterials. The FDA has given its approval to sealants that contain both bovine collagen and bovine thrombin. [8] Although collagen is found all throughout body, various tissues are preferred for their high protein content when creating both medicinal and non-medical items. collagen is used in biomedicine because it has a positive impact on blood clotting, wound healing, and antigenicity (9).

Gelatin-Based Adhesive: A non-toxic and biodegradable biomass resource, gelatin is a multi-stage hydrolysate of collagen. However, its usage in adhesives has always been constrained due to its brittleness and inadequate water resistance. To begin addressing this issue, the epoxy-terminated hyperbranched polymers (EHPAE) were first chosen as a cross-linking agent to modify the gelatin (GE) isolated from leather solid wastes. This allowed for the development of a number of unique, ecologically friendly gelatin-based adhesives. [10]

Dextran Based Adhesive: To produce a hydrogel that is used as a tissue adhesive, it is generally mixed with PEG or chitosan. The amine groups in the remaining dextran aldehyde molecules and the tissue react to produce imines, in which dextran can be oxidised to dextran aldehyde and it binds to the tissue. Less than a minute is needed to complete this reaction. These adhesives' advantages include low cytotoxicity and inflammatory reaction, in addition to being biodegradable. [11]

Albumin Based Adhesive: When the two chemicals are mixed, glutaraldehyde interacts with the lysine residues in albumin; the reaction takes place in 20–30 seconds. Albumin was found to be more stable than fibrin in early experiments with PEG-derivative cross-linked albumin adhesives. In order to create a flexible mechanical seal independent of the body's clotting cascade, the glutaraldehyde molecules covalently bind (crosslink) the BSA molecules to each other and, upon application, to the tissue proteins at the healing site[12].

Chitosan Based Adhesive: Chitosan is soluble in acidic solutions but insoluble at neutral pH levels. Chitosan's usefulness as a sunscreen by acting as a filter has been investigated[13]. It is possible to think of chitosan as a suitable adhesive. Consideration must be given to the adhesion's microscopic and macroscopic components. Before application, the adhesive can be thought of as liquid, and it hardens once it comes into contact with the adherend[14].

V. INGREDIENT OF MARKETED FORMULATIONS:

A .figure:

Types	Ingredient	Reference
Pressure Sensitive	Rubber based: Natural (Isoprene) ,Butyl	[21]
Thermoplastic	Polyurethane, Polychloroprene, Acrylic, Nitrile	[21]
Thermoset	part polyurethanes-Silicones, Epoxies	[21]
Polymer	Polyurethanes , Acrylics , Epoxies Polychloroprenes , Natural rubber , Styrenated Block Copolymers , Cyanoacrylates , Silicones	[21]
Chain Extender	Polyoxypropylene glycol, Polytetramethylene ether glycol, Polycaprolactones , Castor oil, Trimethylolpropane ,1,4-Butanediol	[21]
Isocyanate	Diphenylmethane 4,4'-Diisocyanate (MDI) ,Toluene Diisocyanate (TDI) ,Hexamethylene Diisocyanate (HDI) , Isophorone Diisocyanate (IPDI)	[21]
Acrylic monomer	Acrylic acid, Methyl acrylate ,Ethyl acrylate ,	[21]

	2-Ethylhexyl acrylate ,Methyl methacrylate	
Free Radicle Initiator	Cumyl peroxide, Benzoyl peroxide , tert-Butyl hydroperoxide , tert-Butyl perbenzoate	[21]

VI. DIFFERENT THEORIES OF ADHESION

According to mechanical theory, adhesion takes place when adhesives penetrate pores, cracks, and other surface flaws on the substrate's or adherend's surface. The glue frees the air that has been trapped at the interface. Thus, it can be inferred that an adhesive capable of penetrating the surface roughness of two adherends can bind them together. The "mechanical interlocking" of the adherends and adhesive increases the binding strength of the adhesive [16].

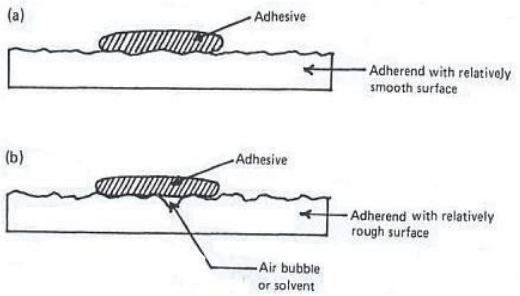
According to Adsorption Theory, the chemisorbed and physisorbed atomic and molecular species that exist at a contact are used in adsorption theory to explain the attractive forces between materials. This theory essentially defines adhesion as one specific characteristic of a phase contact where polar molecules or groupings will be oriented in an orderly manner. The orientation, induction, and dispersion effects are the van de Waals forces, which are initially at effect in this system. A molecule that is strong enough to include a polar group and a non-polar component as separate and distinct entities will orient itself when it approaches an interface where the diel Dectic constant changes. [17]

Electrical Theory: According to this theory, adhesive attraction forces are explained by electrostatic forces at an interface. The basis for this is the process of the formation of an electrical double layer at the interface of two materials. The opposition to separation can be related to these forces. The occurrence of electrical discharges during the removal of an adhesive from a substrate gives support to this theory. When compared to chemical bonding, the electronic mechanism's contribution to adhesion in non-metallic systems has been evaluated and calculated to be low..

Diffusion Theory: According to this idea, adhesion is caused by interactions between and within the molecules of the adherend and adhesive. The diffusion theory is most helpful when both the adherend and the adhesive are polymers with relatively long-chain molecules that may migrate. Diffusion will occur if and to what extent depending on the materials utilised and the bonding conditions. Typically, the dispersed interphase layer's thickness falls between 10 and 1,000 [16]. As there is no discontinuity in the physical properties, there is no stress concentration at the interface. When the solubility characteristics of the adhesive and the adherend are compatible, bond strength is maximised.

The adherence of polyethylene and polypropylene to butyl rubber serves as an useful example. When two polymers are joined at temperatures below the polyolefin's melting point, the adhesive bond is weak. When the adhesion process occurs above the melting point of polyethylene and polypropylene, bond strength significantly increases. The connection among both bonding temperature and bond strength (peel strength).

Wetting Theory: Wetting is the process of establishing continuous contact between the adherend and the adhesive. The surface treatment of materials is performed so that an adhesive can wet a solid surface by using a lower surface tension than the solid's critical surface tension[16].



When the adhesive permeates into the substrate surface's valleys and cracks, there is good wetting. Poor wetting happens when the adhesive enters the valley, which reduces the actual area in contact with the adherend and lowers the total strength of the joint. The strength of the adhesive bond is decreased as a result of incomplete wetting, which causes interfacial problems. The strongest connection is produced with complete wetting.

Acid-Base Theory: The acid-base theory, an unique type interaction, was just recently discovered. It is

based on the idea of Lewis acid and base in chemistry. According to Lewis, a base is a chemical that can contribute an electron pair, while an acid is a substance that can take an electron pair from an acid. The polar attraction of Lewis acids and bases (i.e., electron-rich and electron-poor elements) at the contact is also what produces adhesion, according to the acid/base theory[16].

Weak Boundary Layer Theory: The environment, the adherend, the adhesive, or any combination of the three could be the cause of weak boundary layers. If an impurity forms near to the bonding surface and produces a weak bond with the substrate, weak boundary layers may develop in the adhesive or adherend. Despite appearing to happen at the adhesive adherend interface, failure really occurs at the weak boundary layer. [16]. When the adhesive does not wet the substrate, a weak boundary layer (air) is trapped at the interface, causing a reduction in joint strength.

QUALITY CONTROL TEST OF ADHESIVES:

1.Spreadability Measurement:

By measuring the spreading diameter of 1 g of the formulation after 1 minute between two 20 20 cm glass plates, the spreading capability of the formulations was determined 48 hours after preparation. The upper plate's mass was standardised at 125 g. For this, the following equation was utilized. $S = m\times l/t$

In which S is the formulation's spreadability, m is the weight (g) connected to the upper plate, l are the glass plates' lengths (cm), and t are the seconds needed for the plates to move their whole length[23].

2.Determination of PH: One g of adhesive were weighed and diluted 10 times with isopropyl alcohol. Then, pH of adhesive was measured with pH-meter[23].

3.Viscocity test: Viscocity is a measure of a liquid resistance to flow, which describe the internal friction of a moving fluid, Low viscocity adhesive will flow more readily than high viscocity. viscocity highly depend on temperature decrease with increase temperature, we will measure the viscocity at 25˚c in cps coming in a wide range of viscocities from as low as 200cps to in excess of 500,000cps.

4.Evaluation of Peel Strength: The delamination strength of thin films to silicon substrates has been the focus of peeling in the microelectronics industry. Peel has a variety of fascinating uses in fields including cell adhesion and motility as well as biomaterial adhesion. For the purpose of investigating the adherence of ductile thin films to ceramic substrates, Wei and Zhao created an experimental peel setup. The effects of film thickness, peel angle, and adhesive layer thickness on the system's overall energy release rate are investigated through peel experiments[22]. In the 90-degree peel test, the two glued components are separated while maintaining a constant 900-degree angle. Across the length of the specimen, the average load needed to separate the two is noted. In the 180-degree peel test, the two glued components are peeled apart at a steady 1800-degree angle. Throughout the length of the specimen, the average force needed to separate the two is measured and given as N/25mm.

5.Fourier transform infrared (FTIR) Spectroscopy:

The adhesive was cured in an oven at 120 ± 2 ˚C until a constant weight was obtained, and was then ground into a powder. FTIR spectra of the different cured adhesives were recorded on a Nicolet 7600 spectrometer from 500 to 4000 cm1 with 4 cm1 resolution using 32 scans[24].

6.X-Ray Diffraction(XRD):

The XRD analysis of HMA showed that it was a partially crystalline compound, with a peak on an amorphous hump which is the characteristic of a partially crystalline substance[25].

7.Atomic force microscopy (AFM):

The adhesives were cured in an oven at 120 ± 2 ˚C until a constant weight was obtained, and were then ground into powders. The AFM samples were prepared by making pressed powder pellets using a compressing machine . AFM measurements were performed with Shimadzu SPM-9600 equipment to evaluate the surface roughness of the adhesive. AFM images were obtained at room temperature in tapping mode with a scan rate of 1 Hz and using Si tips with a curvature radius of less than 10 nm and a spring constant of 42 N \m square[24].

8.Scanning electron microscopy (SEM):

The adhesive sample was poured onto a piece of aluminum foil and dried in an oven at 120± 2 ˚C until a constant weight was achieved. scanning electron microscope was used to observe the fractured surface of

the adhesive. The surface was sputter coated with gold prior to examining it under the microscope[24].

9.Patch Test: Skin on the upper back with an absence of scars, moles, freckles and any other skin anomalies was tested. The sample (25 µL) was applied four times to the same site (induction site) over four consecutive weeks under an occlusive patch, followed by a challenge phase after a minimal one-week rest period. The patch test results were interpreted according to the International Contact Dermatitis Research Group (ICDRG) guidelines [26].

10.Determination of Adhesive Ability: Pieces of cowhide were cut into sizes of 100×25×2 mm and 100×25×2 mm, respectively. The adhesive samples were applied between two pieces of cowhide and allowed to dry for 30 min. The tensile strengths of the adhesive samples were measured by an Instron universal testing machine (Model 5566, Instron Corp., Canton, MA, USA) at a crosshead speed of 2.0 mm/min. A force of 1,000 lb was applied to the load cell. Tensile strength was expressed in MPa and calculated by dividing the maximum load (N) by the initial cross-sectional area (m2) of the specimen. This procedure was repeated five times for each type of sample[26].

11. Falling liquid film method:
Sprague-Dawley rats' small intestine was removed, divided into pieces along its length with surgical scissors, cleaned with saline water, and then spread along 1" internal diametric Tygon tubes. These tubes were positioned over a plastic foam bed with a 78° angle of inclination. After the chopped intestines were spread out over the Tygon plates, loose mucus from the intestine was eliminated using a perfusion pump. The sample solutions were then collected from the field to start the particle counting process after a 2 minute delay of coating the intestines with the prepared buffer solution. It was seen that a foreign substance, possibly mucus, was present on the intestine's surface. For detecting the bioadhesion phenomena over the gut surface that is covered in particles, An Coulter particle counter was used to count the number of particles in 0.5 ml of recovered samples.

12. Thumb Test: The adhesiveness is qualitatively assessed by measuring how challenging it is to remove one's thumb from an adhesive as a function of pressure and contact time. On mucoadhesive potential, it offers helpful information.

13. Mucoadhesive Studies: Bernkop-Schnurch and steininger et al. have developed a brand-new technique to assess the tablet's cohesiveness and its ability to adhere to the mucosa. The freshly excised intestinal porcine mucosa, which had been stretched on a stainless steel cylinder, was affixed to the produced tablets (apparatus 4 cylinder, USPXXII).
The cylinder was then placed in the USP-compliant dissolve equipment with 100 mm of Tris-HCl buffered saline (TBS). With 250 rpm, the fully submerged cylinder was stirred. Within a 10-hour window, the tablet's detachment, disintegration, or erosin was witnessed and documented.

ADVANTAGES:
1. Fast and cheap joining
2. Uniform stress distribution.
3. Possibility to join large surfaces
4. Ability to join different materials.
5. Possibility to join very thin adherent.
6. No contact corrosion.
7. Good damping property.
8. High dynamic strength.
9. Provides joints with smooth contours.

DISADVANTAGE :
1. Limited stability to heat.
2. High strength adhesive are often brittle.
3. Long term use may alter the properties.
4. Cleaning and surface preparation of the adherent is necessary in many cases.
5. The bond does not permit visual examination of the bond area.
6. Rigid process control, including emphasis on cleanliness, is required for most adhesives.
7. The useful life of the adhesive joint depends on the environment to which it is exposed.
8. Natural or vegetable-origin adhesives are subject to attack by bacteria, mold, rodents, or vermin.[18]

APPLICATIONS:
The primary use of adhesives for bonding is joining metal to non-metal, particularly plastics. Used as a substitute for riveting in the construction of aeroplanes. Commonly used in the assembly of aircraft honeycomb structures and the anchoring of stiffeners to the aircraft skin.

Often used to create the smooth surfaces for internal aircraft structural manufacturing.
for sonic-speed aircraft.
Used in ceramic tiles.
It is also used in the HVAV sector.
The wound closure technique uses an adhesive made of collagen.
It is also employed in the cosmetics business as wig adhesive.
Hot melt or thermosetting adhesives are the most common types of adhesives that come in pellet form. Often, these need to be heated and melted before being sprayed. In orthodontic treatment, adhesive adhesives are also used to affix brackets to the teeth and to hold jacket crowns, a type of artificial tooth, in place. Since they allow the dentist to rebuild the tooth without removing a lot of good tissue, adhesive materials are more clinically conservative. Dental adhesives such as glassionomer and zinc polycarboxylate cements as well as dentine bonding agents are used to adhere composite resin restorations to the tooth's dentine[17].
Corrugated boxes, wallpaper paste, and laminating all require starch glue. Dextrin adhesives work well for making paper, envelopes, and bottle labels. In order to satisfy various needs, liquid glues come in high viscosity kinds as well as a variety of capabilities. The majority of adhesives used in labelling applications are water-based ones that incorporate starch, dextrin, and/or casein. Most typical labelling applications that don't require a lot of precision employ pure starch and dextrin glues. In addition, starch glues are frequently employed in the manufacture of corrugated board. Plastic bottle adhesives based on colloidal solutions with tackifier resins are also acceptable. For the tail-tie bonding of toilet and tissue paper rolls, water-based adhesives with cellulose or cellulose derivatives are frequently used to bind paper in tissue and towel applications. Additional uses for hotmelt include sealing plastic caps onto bricks (like milk) or attaching straws or bag-in-boxes (juices, wine). Double-sided tapes and reclosable food packs are frequently manufactured using hotmelts. Packaging of dairy items including yoghurts, plastic trays, and instant noodle cups are some more applications for heatseals, along with pharmaceutical blister applications and flexible laminated foil packages[18].
Adhesives are used in medical equipment for a variety of purposes, including joining surgical tools together, attaching plastic soles to the soles of cast boots, attaching rubber bumpers to the bottoms of crutches or walking sticks, and more. In the construction of medical devices, pressure sensitive adhesives (PSA) are now often utilised. They require pressure to make a solid bond when initially applied.
In a number of surgical procedures, such as the closure of lacerations, vascular and intestinal anastomoses, and the glueing of skin flaps to the intestines to prevent fluid buildup, surgical adhesives are used to re-approximate injured tissues. [19] When compared to suture treatments, fibrin glue has been shown to significantly reduce operating time and recurrence rate with no difference in complication rate. [19]

VII. CONCLUSION

Adhesives have been used in industry for decades; but, the environmental influence of adhesives has not been investigated up until recently. Therefore, one must emphasise on the new or combination adhesives that necessity allow obtaining environmentally safe and high-quality adhesives .
Due to the limited raw materials and the negative impact of synthetic compounds on both human health and environment, natural and renewable resources required for the production of adhesives. From above study we can help to develop bioadhesive by environmental, fastly achieve and safety point of view for prevention of side effect and economic aspect.

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