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IMPACTS OF FUNCTIONAL GROUPS ON THE INTERMOLECULAR FORCES OF ATTRACTION IN ANIMAL GLUE OBTAINED FROM THE FEMUR BONES OF COW *(BOS TAURUS*)

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ABSTRACT

Functional groups in samples obtained from the femur bone of Cow (Bos taurus) were determined using Shidmazu Fourier transform infrared (FT-IR) – 8300 spectroscopy. The bones were crushed, washed properly with warm water and immersed in lime solution for three days. Samples were then treated with dilute 20% hydrochloric acid (to release the collagen in the bone) dried and crushed to a particle size of 0.02 mm. Results obtained from FT-IR analyses shows the presence of alcohol, alkyne, carboxylic acid, phosphate, 1,3 disubstituted aromatics and haloalkanes at wavelength ranges of 3550 – 3200 cm^{-1}, 2360 – 2014 cm^{-1}, 1420 – 1320 cm^{-1}, 1099 – 1039 cm^{-1}, 970 – 890 cm^{-1} and 705 – 550 cm^{-1} respectively. The presence of functional groups with highly electronegative atoms such as two, three and four oxygen atoms in carboxylic acid, anhydrides and phosphates respectively in addition to the presence of halogens in haloalkanes and multiple bonds in alkyne, nitrile and alkenes increases the polarizability of the compounds thereby strengthening the weak intermolecular forces of attraction such as hydrogen bond and Van der Waal forces of the adhesive molecules which ultimately increases the adhesive strength and the force of cohesion of the animal glue produced.

Keywords: Adhesive, polarizability, bonding, adhesion, cohesion, infrared, spectroscopy.

INTRODUCTION

Adhesives are substances with the ability to bind or unite two materials together by sticking strongly to the surface of both. There are other binding techniques such as sewing, wielding, mechanical fastening etc however the use of adhesives offers certain advantages over the other techniques. These advantages include the ability to bind different materials together, effective distribution of stress across a joint, greater flexibility in design as well as affordability (Kumooka, 2010). Adhesives can be classified as natural or synthetic based on the source of the raw materials. Adhesives obtained from natural source includes plant resins, glues from animal bones, hide and skin as well as adhesives from mineral (inorganic) sources while synthetic adhesives are polymers such as elastomers, thermoplastics and thermosets. These adhesives either natural or synthetic can be further classified based on other factors such as physical / chemical composition, structure, load bearing capability, mode of bonding, response to solvent and pressure etc (Mehltretter et al. 2011; Moghaddam and Thormann, 2020). Animal glue is a natural adhesive obtained from mammalian collagen which is the main protein constituent of skin, muscle, and bone. Animal glue is the lower molecular weight material produced after treating collagen with either hot water, acids and alkalis. It is usually less pure and darker in color compared to the high molecular weight product called gelatin which is edible and used for photographic purposes (Nam et al., 2018; Sakayanagi et al., 2003). The adhesive strength of an adhesive is the potential of the adhesive to stick to a surface and bond two surfaces together it can also be defined as the maximum interfacial tensile stress between two surfaces (Hall, 2010). The adhesive strength is determined by several factors which includes method of adhesion, type of stress acting on completed bonds, stress orientation to the adhesive as well as the rate at which they are applied. The adhesive strength of an adhesive plays a vital role in its application and durability hence the need to ascertain the chemical constituents such as functional groups and their impact on the factors affecting the strength of adhesion (Salmimi et al., 2020). An adhesive is a non-metallic binding agent that acts through the processes of adhesion and cohesion. The state of the adhesive differs in both processes of adhesion and cohesion hence the difference in this state is referred to as the transition zone. Adhesion has to do with the actual area of contact of the adhesive and substrate whereas cohesion refers to the inner strength of the adhesive orchestrated by both bonding and non-bonding forces as shown in Figure 1. The state of the adhesive at the surface of the substrate is referred to as the transition zone. The macroscopic properties, structure and composition of the adhesive continuously changes in the transition zone between the adhesion zone and cohesion zone (Saman et al., 2021; Watts et al., 2019). The principles of adhesion arise from the molecular interactions between the surface of the substrate and the adhesive whereas the cohesion zone comprises of the chemical bonds within the adhesive polymers, chemical bonds resulting from crosslinking of the polymer, intermolecular interactions between the molecules in the adhesive as well as mechanical adhesion between various molecules in the adhesive (Goodpaster et al., 2007). These molecular interactions within the adhesive could either be in the form of strong chemical bonds such as covalent, ionic bonds or weak intermolecular interactions such as hydrogen bonds and Van der Waal forces. Just as the weakest link in a chain determines the strength of the chain so also the adhesive strength of an adhesive is ultimately determined by the weak intermolecular forces of interactions within the adhesive (Saman et al., 2021).

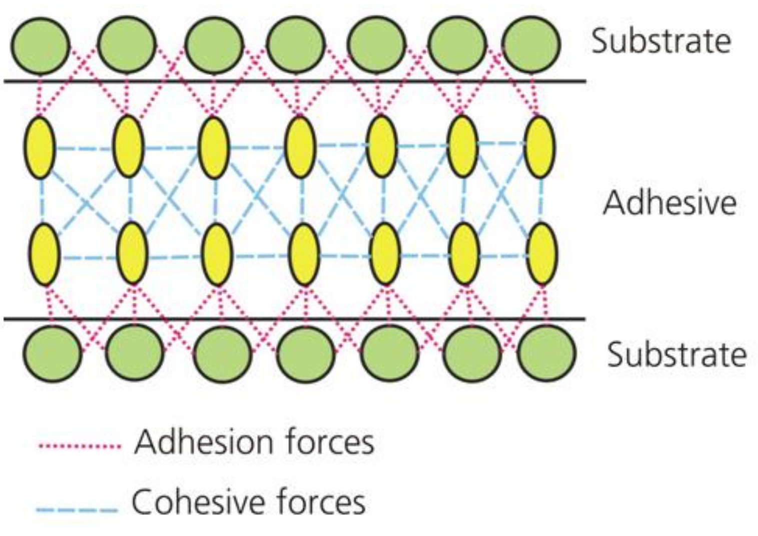

Figure 1: Relationship between forces of adhesion and cohesion

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The aim of this study therefore is to determine the impacts of functional groups on the intermolecular forces of attraction within the molecules of animal glue obtained from the femur bone of cow (Bos taurus) which ultimately determines its adhesive strength. The bones of Mammalia have proven to be one of the sources of animal glue in the past. An in-depth knowledge of these functional groups will be useful in simulating the use of other organic and inorganic materials as adhesives. Figure 2 shows the Femur bone of Cow (Bos taurus).

Figure 2: Femur bone of cow (Bos taurus)

MATERIALS AND METHODS

Sample Collection / Preparation

The femur bones of cow was obtained from the northern part of Nigeria in a village known as *Ningi* In Bauchi State. The bones were reduced to smaller sizes with the use of a mallet and washed properly with warm water at a temperature of 40-45 ^{0}C to get rid of fat and dirt. Thereafter, 400 g of the bone samples were immersed in a 150 g/mol $Ca(OH)_2$, a lime solution previously dissolved in 1000 cm^3 of water for 3 days to get rid of odour and tiny amounts of flesh and hair attached to the bones. The bones were removed from the lime solution after 3 days and washed thoroughly with distilled water to remove the hydrated lime. To control the pH of the sample and breakdown the collagen to glue, samples were treated with dilute (20%) hydrochloric acid (HCl). Samples were dried for two days and crushed to a 0.02 mm mesh size. Inorder to further release the collagen within the bone sample, solution of sample was transferred into a beaker and heated at 70 ^{0}C for 4 hours to obtain samples for Fourier transform (FT-IR) spectroscopic analyses (Nam et al., 2018).

Fourier Transform Infrared (FT-IR) Spectroscopic Analyses of The Femur Bone of Cow (Bos Taurus)

Powdery particles of 0.02 mesh size of dry sample obtained from the femur bone of cow (Bos taurus) were subjected to FT-IR spectroscopic analyses by the solid state method using Shidmazu FT-IR-8300 spectrometer. Samples were characterized using ASTM D2621. Potassium bromide (KBr) equivalent to 100 mg was mixed properly with the sample using small plastic pestle and mortal. The KBr-sample mixture was added to sample compartment and gently squeezed for transparent disc formation. The KBr-sample disc was then placed in the equipment and carefully analyzed to obtain the peaks, retention times and wavelengths which were interpreted to obtain the respective functional groups (Salmimi et al., 2020).

RESULTS AND DISCUSSION

Table 1: Functional groups in Acid treated Femur bone of Cow (Bos taurus)

Wave number (cm^{-1})	Functional groups	Possible compounds
3550 - 3200	O-H	Alcohol
2360 - 2014	CΞC	Alkyne, Nitrile
1420 - 1320	C=C, O-H	Alkenes, phenol, carboxylic acid
1099 - 1039	$PO4^{3-}$, C-O	Phosphate, Anhydride
970 – 890	C=H	Alkene bending of aromatics, 1,3-disubstituted
705 – 550	C-X	Haloalkanes

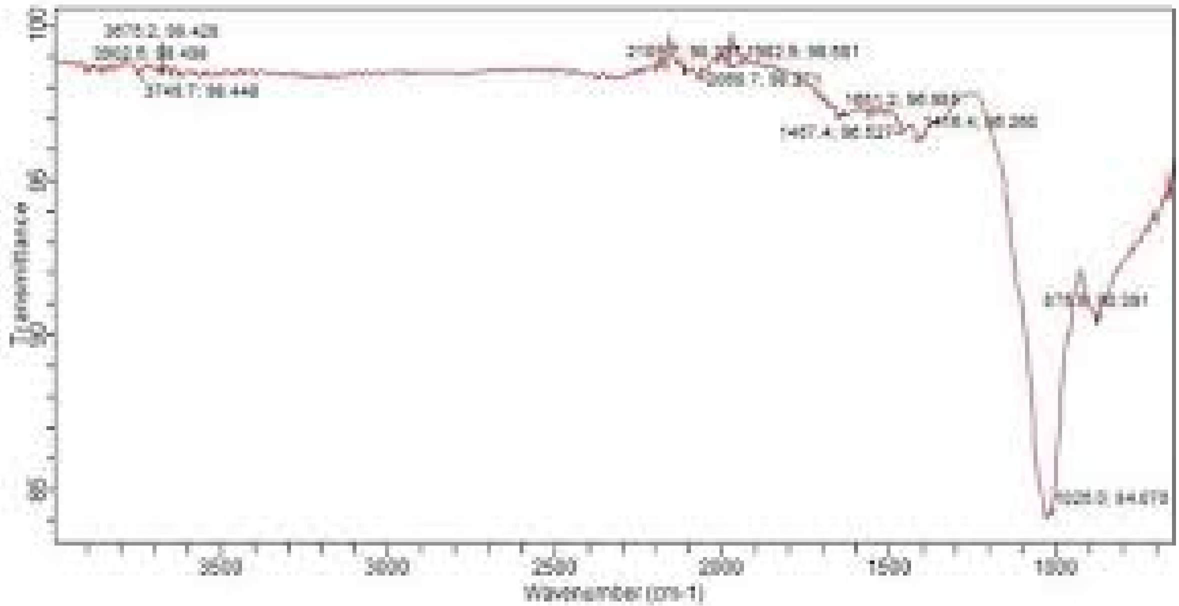

Figure 2: Spectrum of acid treated Femur bone of Cow (Bos taurus)

Functional groups are specific atoms bonded in a certain arrangement thereby giving rise the physical and chemical properties of a compound. Hence a compounds functional group influences both its physical and chemical properties (Saman et al., 2021). Functional groups in acid treated femur bone of Cow (Bos taurus) is shown in Table 1 as indicated by the FTIR spectrum shown in Fig. 2. The table shows the functional groups, the wavenumbers at which the peaks eluted as well as the possible compounds in the sample. Results obtained shows the stretching of the OH^- group by the broad peak eluted at wavenumbers between 3550 – 3200 cm^{-1}, the presence of alkyne and nitrile groups at wavenumbers between 2360 – 2014 cm^{-1}. The observed peaks between 1420 – 1320 cm^{-1} represents alkene and hydroxyl functional groups which can be attributed to the presence of alkenes, phenol and carboxylic acids. The presence of phosphates and anhydrides were indicated by the bands at 1099 - 039 cm^{-1} while the peaks around 970 – 890 cm^{-1} represents the C=H functional group which indicates alkene bending in aromatics as well as 1,3 – disubstituted benzenoids. The presence of Haloalkanes were represented by the peaks at 705 – 550 cm^{-1}. It is worthy to note that irrespective of the strength of the forces of cohesion within an adhesive, it must be less than the force of adhesion between the adhesive and the substrate in order for the adhesive to be strongly bonded to the substrate

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(Hall, 2010). The force of adhesion between the adhesive and the substrate are influenced by certain factors which includes phase changes of the adhesive, degree of wetting of the substrate which ultimately affects its surface tension, compatibility of the substrate and the adhesive and most importantly the intermolecular forces of interaction between the adhesive molecules (Arua and Blum, 2018). An adhesive must undergo a phase change from liquid to solid to ensure adequate adhesion to the substrate. The substrate must be wetted adequately to reduce its surface tension which ultimately improves the strength of the adhesive. The adhesive and the substrate must be compatible such that the adhesive should adequately wet the substrate to ensure adequate adhesion. All the aforementioned factors are very important in determining the forces of adhesion between the adhesive and the substrate however they do not in any way change the atoms of the molecules that makes up the adhesive (Nam et al., 2018; Sakayanagi et al., 2003).

The presence of electronegative atoms like oxygen in functional groups such as hydroxyl (OH^-), carboxylic (COOH), phosphate (PO_4^{3-}) and anhydrides (CO) as shown in table 1 increases the polarizability of these groups which in turn increases their weak intermolecular forces of attraction such as hydrogen bond and Van der Waal forces. The presence of these functional groups within the adhesive molecules therefore increases the forces of cohesion within the molecules which in turn increases the adhesive strength (Saman et al., 2021). The presence of multiple bonds in alkenes, alkynes, aromatics, nitriles shown in table 1 also increases the polarizability of these compounds. Polarization which refers to the bond formed between two atoms with different electron density increases with increase in electron density difference between the atoms. Hence the higher the difference in electronegativity between the atoms of the compound the higher its polarizability and this is responsible in the bond strength of weak intermolecular forces of attraction such as hydrogen bond and Van der Waal forces within the adhesive molecules (Zieba-Palus et al., 2016). The presence of these functional groups (as shown in table 1) in the femur bone of cow (Bos taurus) affirms the possibility of the animal glue produced to form a strong cohesion zone which is ultimately dependent on the strength of the intermolecular forces of attraction (Nam et al., 2018). A couple of quality control and improvement processes can be carried out in the production of animal glue obtained from the femur bone of cow (Bos taurus) for instance polyvinyl acetate (PVA) can be added at a volume of 1:3 to the glue (or more) to improve the jelly like nature, elasticity and flexibilty of the glue. The prevention of bacterial growth and mold can be achieved with the addition of 10 ml formaldehyde. These compounds in addition to their desired functions introduces polar groups which improves the adhesive strenght of the adhesive (Kumooka, 2010).

CONCLUSION

Adhesives function through the processes of adhesion and cohesion. The force of adhesion exists between the adhesive molecules and the substrate while the force of cohesion exists between the intermolecular forces in the adhesive, and it is also vital in determining the strength of the adhesive with respect to the substrate. The functional groups in animal glue obtained from the femur bone of cow (Bos taurus) plays a predominant role in determining the strength of the intermolecular forces of interaction between the adhesive molecules. Highly polarizable functional groups such as Alcohols, alkyne, nitrile, carboxylic, haloalkanes, anhydrides and phosphate groups were identified using FT-IR spectroscopic analyses. The presence of highly electronegative atoms as seen in four atoms of oxygen in phosphate, three atoms of oxygen in anhydrides, two atoms of oxygen in carboxylic acid, presence of highly electronegative atoms like halides in haloalkanes as well as highly unsaturated compounds such as alkynes, nitriles contribute to the polarizability of these compounds. The higher the polarizability of the atoms of the molecules the stronger the intermolecular force of attraction such as hydrogen bond and Van der Waal forces.

REFERENCES

Arua, U.N. and Blum F.D. (2018) Disruptions in the crystallinity of poly(lauryl methacrylate)due to adsorption on silica. *Journal of Polymer Science Part B: 56 (1) 89-96.*

Goodpaster, J.V., Sturdevant, A.B., Andrews, K.L., Briley, E.M. and Brun-Conti, L. (2007) Identification and comparison of electrical tapes using instrumental and statistical techniques: I Microscopic surface texture and elemental composition. *Journal of Forensic Science 52: 610-629.*

Hall, M.R. (2010) Materials for Energy Efficiency and Thermal Comfort in Buildings. Part II: Materials and sustainable technologies: improving energy efficiency and thermal comfort in the built environment. *Woodhead Publishing Series in Energy. pp 709-734.*

Kumooka, Y. (2010) Classification of OPP adhesive tapes according to MALDI mass spectra of adhesives. *Forensic Science International 197: 75-79.*

Mehltretter, A.H., Bradley, M.J. and Wright, D.M. (2011) Analysis and discrimination of electrical tapes: Part I. Adhesives. *Journal of Forensic Science 56: 82-94.*

Moghaddam, S.Z. and Thormann, E. (2020) Surface forces and friction tuned by thermo-responsive polymer films. *Current Opinion in Colloid & Interface Science 47, 27-45.*

Nam, C., Zimudzi, T.Z., Wiencek, R.A., Chung, T.C.M. and Hickner, M.A. (2018) Improved ATR-FTIR detection of hydrocarbons in water with semi-crystalline polyolefin coatings on ATR elements. *Analyst 22:143*

Sakayanagi, M., Konda, Y., Watanabe, K. and Harigaya, Y. (2003) Identification of pressure-sensitive adhesive polypropylene tape. *Journal Forensic Science 48: 68-76*

Salmimi, A.S., Kah, H.C. and Ahmad, F.L.A. (2020) Profiling of cured residue of solvent based adhesives by attenuated total reflectance–Fourier transform infrared with chemometrics for forensic investigation. *Journal of Forensic Sciences 1556-4029.*

Saman, S.A., Chang, K.H. and Abdullah, A. (2021) Profiling of cured residue of solvent- based adhesives by attenuated total reflectance-Fourier transform infrared spectroscopy with chemometrics for forensic investigation. *Journal of forensic sciences 66(2), pp608–618.*

Watts, K.E., Blackburn, T.J. and Pemberton, J.E. (2019). Optical Spectroscopy of Surfaces, Interfaces, and Thin Films: A Status Report. *Analytical Chemistry 91 (7), 4235-4265.*

Zieba-Palus, J., Kowalski, R. and Nowinska, S. (2016) Aplication of infrared spectroscopy and pyrolysis gas chromatography for characterization of adhesive tapes. *Journal of Molecular Structure 1126: 232-239*