Effect of Gum Arabic on Water Resistance and Strength of Sodium Silicate as Wood Adhesive

Manju Choudhary[1], Meenakshi[2]* Bhupendra Pal[3]

[1,2] Department of Chemistry, University of Rajasthan,Jaipur, Rajasthan, India – 302004
[3]Govt. Polytechnic College, Karauli, Rajasthan, India- 322255

Address for Correspondence: Dr. Meenakshi, Assistant Professor, Department of Chemistry, University of Rajasthan, Jaipur, Rajasthan, India – 302004.
Email: meenakshialwaraj@gmail.com

ABSTRACT: Sodium silicate has outstanding binding properties and prospective applications in a wide range of fields because it is non-toxic, fireproof, odorless, and free of volatile organic compounds. However, its poor water resistance has limited its use as an adhesive in the wood industry on a large scale. In order to improve the bonding properties of sodium silicate and teak wood three sets of sodium silicate adhesives (simple sodium silicate, modified sodium silicate with silica gel G, and gum arabic with modified sodium silicate) were made. The results showed that modified sodium silicate with 4% gum arabic works best for tensile strength and 6% gum arabic works best for water resistance with reference to 24 hour water absorption rate. Results of FT-IR data showed that gum arabic was successfully mixed into the silicate structure, having good thermal stability in the range of 27° C – 800°C, as supported by TGA results.

Keywords: Wood adhesive, Sodium silicate, Moisture resistance, Tensile strength, Gum arabic

INTRODUCTION

An adhesive is a non-metallic material that is applied to one or both surfaces of two different objects in order to bind them together and prevent them from being separated. The adhesive junction typically comprises a polymeric component that is attached to the substrate by chemical bonding, physiochemical attractions, and physical interlinking. [1] These days, the wood industry uses a lot of petrochemical-derived organic adhesives. These adhesives, such as urea-formaldehyde resin, melamine formaldehyde resin, phenolic resin, and others, have exceptional adhesive qualities, such as strong bonding strength and good water resistance, but the majority of organic adhesives also contain harmful materials to the environment and human health.[2-4] Due to the worsening global energy crisis and growing environmental consciousness, organic adhesives will eventually be replaced by environmentally friendly adhesives.

The current organic adhesives sector is compatible with inexpensive, environmentally beneficial, non-burning inorganic adhesives.[5] Silicate adhesives, particularly Sodium silicate (water glass), is the most promising of all the inorganic adhesives now in the market.[6] Sodium silicate has many excellent qualities, including an abundance of natural resources, strong adhesion, and ease of handling. [7-12]

Commercial sodium silicate has all the necessary characteristics of an effective adhesive, including the ability to be applied to the materials to be joined easily, suitably, and flexibly. Sodium silicate has the capacity to set in the appropriate way and amount of time with the development of a bond of the desired strength. Sodium silicate adhesive can be chosen with any required viscosity and setting time. Additionally, its composition can be changed to allow products manufactured with the help to survive any certain temperature and humidity level. It is immune from any form of bacterial activity and does not decompose. It is fire proof. It is colorless which is special importance in the manufacture of built up paper board and corrugated containers for food products. Sodium silicate adhesive is cheap, both relatively as to the quantity required for uniting materials and absolutely. It is easiest to use, as this does not require the application of heat, and may thus be kept ready for immediate use.[13]

It is not hazardous, explosive, or flammable. High bonding strength, low adhesive stress, strong temperature resistance, and lack of volatile organic compounds are all characteristics of Sodium silicate adhesive. The metal, ceramic, glass, stone, and wood industries all can use it for bonding. The practical application of Sodium silicate as a wood glue is constrained due to its hygroscopic nature. [14-16] Additionally, its glue line is rigid and inflexible. Its use against organic adhesives in the wood industry was restricted by several of these problems.

However, little research has been done on the use of sodium silicate adhesive in the wood-based sector. L. Qiangqiang et al. investigated the physical and mechanical properties of sodium silicate compound with glucose-urea-melamine resin modification on poplar wood.[17] X L Zhang et al. studied the research of sodium silicate adhesive using carboxymethylcellulose (CMC) additive.[18] Suleman et al. studied the chemically modified soluble sodium silicate as an adhesive for solid wood panels.[19] X L Zhang et al. investigated the effect of curing technology on bonding properties of silicate wood adhesive.[20] X L Zhang et al. studied the effect of ammonium stearate on bonding properties of sodium silicate.[21] X L Zhang et al. studied nanoparticles (nano-silica additive with nano-magnesia as curing agent and nanoattapulgite as skeleton material) to modify Na_2SiO_3 adhesive.[22] B Neyses et al. investigated the research to reduce the set recovery and the hardness of surface densified scots pine treated with sodium silicate, sodium hydroxide, ionic liquids or methacrylate resin to modification.[23] P Yucheng et al. studied the research on silicate solution with cellulose nanofibrils effect on Southern pine.[24] Y. Cheumani et al. studied the research with sodium silicate and sol-silicate iorganic-organic hybrid dispersion coating preparation, surface coating and water resistance on wood.[25]

Based on the results of the preceding literature review, sodium silicate may be modified in order to produce high-performance adhesive. In this work, the effects of adding gum arabic as an additive and silica gel G as a curing agent are investigated. In order to evaluate the Na_2SiO_3 adhesion potential, its bonding strength and water resistance were both analyzed. Investigations into the interactions of gum arabic, silica gel G, and Na_2SiO_3 in the adhesive structure revealed that the cured morphology and thermal properties support the concept that adding gum arabic will enhance the performance of Na_2SiO_3 adhesive.

MATERIALS AND METHODS

Materials:

- **Sodium silicate:** 52° Be concentration of translucent sodium silicate solution works best for adhesive work. It was collected from the local market of Jaipur, Rajasthan. The chemical analysis of Sodium silicate is: SiO_2 = 33.66%, Na_2O = 13.65%, Viscosity = 1553.23 mPa.s, Specific gravity = 1.54, Weight ratio SiO_2/Na_2O = 2.47:1, Total solid = 26%, pH = 11.7.
- **Gum arabic:** Powder for gum arabic was collected from local market of Jaipur, Rajasthan, India.
- **Silica gel G:** Silica gel G was obtained from the chemical store of Department of Chemistry, University of Rajasthan, Jaipur, Rajasthan, India.
- **Wood:** Wood of *Tectona grandis* (teak) was collected from local timber industry of Jaipur, Rajasthan, India.

Methods:

- **Preparation of wood samples**: Wood samples were prepared according to IS 11215 (1991) and IS 1708 (1986) having dimensions of 150 mm x 25 mm x 3 mm and 13% moisture content.[26-27]
- **Formation of modified Sodium silicate adhesive (MSS):** 80 ml of water glass was mixed with 20 ml of silica gel in a dry and clean glass beaker to form sodium silicate solution.
- **Formation of Sodium silicate adhesive with gum Arabic (MSSGA):** In order to find the effect of gum arabic on adhesive strength of sodium silicate, five clean and dry beakers are taken and numbered them sample no.1 to 5. Modified Sodium silicate were poured in beaker no. 1 to 5 and then 2, 4, 6, 8, and 10 gram of gum arabic was added to bowl no. 1 to 5 respectively (Figure 1). The samples of experiment were shown in Table 1.The prepared modified sodium silicate adhesives with different percentages of gum arabic are shown in Figure1.

Table 1: The samples of experiments

Component	Sample number				
	S1	S2	S3	S4	S5
Water glass (ml)	80	80	80	80	80
Silica gel G (gm)	20	20	20	20	20
Gum Arabic (gm)	2	4	6	8	10

Figure 1: Prepared samples of modified sodium silicate with gum arabic (2% to 10%)

- **Moisture resistance investigation:** To investigate the effect of gum arabic on water resistance of sodium silicate, teak wood blocks having 13% moisture content were glued using double coating of simple sodium silicate (SS), modified sodium silicate with silica gel G (MSS), and modified sodium silicate containing various amounts of gum arabic (MSSGA) under load pressures of 0.5-0.9 MPa at 30 °C for 24 hours (Figure 2).Then, water absorption rates with various time intervals were calculated by measuring the ratio of the difference in mass before and after 24 hours of immersion in water according to Indian standards (IS 848: 2006; IS 851: 1978). [28-29] Figure 4 & 5 includes the results.

Figure 2: Preparation of wood blocks for water resistance investigation

- **Tensile strength investigation:** Effect of gum arabic on bonding performance of sodium silicate was determined by tensile strength investigation. Teak wood blocks (moisture content of 13% with dimensions of 150 mm×25 mm×3 mm) were glued by double coating of SS, MSS, and MSSGA containing gum arabic 2% to 10%, under pressures load of 0.5-0.9 MPa at 30℃ for 24h and investigated with Instron-5967 Universal testing machine (Fig. 3). Results are included in Fig. 6.

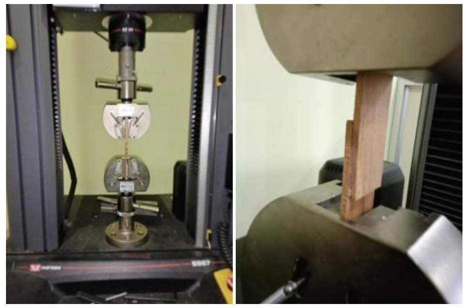

Figure 3: Tensile strength testing of sodium silicate adhesive on wood blocks

Both moisture resistance and tensile strength investigations were repeated for six times for each type of experiment and then average results were reported.

- **Spectral analysis**
    1) **Fourier transform-infrared spectroscopy (FT-IR) analysis:** Formation of new bonds by intermixing of compounds was dertermined by using FT-IR spectral analysis. To study the samples ATR mode is used. Each sample was scanned 32 times over a region of 4000-400 cm^{-1} at a resolution of 4 cm^{-1} to obtain FT-IR spectrum.
    2) **Scanning electron microscopy (SEM) analysis:** Surfaces of cured films of the adhesive samples were studied by SEM under high vacuum mode.
    3) **Thermo gravimetric analysis (TGA):** Stability of the adhesive samples against thermal energy was determined by thermo gravimetric analysis. Samples were heated from room temperature to 800 ℃ at a rate of 15℃/min under nitrogen gas flowing at 20 mL/min.

RESULTS AND DISCUSSION

Principle of the modification:

- **Role of Silica gel G as curing on the adhesion properties of Na_2SiO_3 wood adhesive:** Sodium silicate adhesive is usually supplied as a viscous water solution and adhesive bond forms by the evaporation of water. After fully curing, the Na_2SiO_3 glue transforms into a transparent, brittle substance. Preliminary research indicates that when used as wood glue, curing flaws such as stress cracks and bubbles in the binding line are immediately identifiable. Therefore, it is crucial to reduce the brittleness of Na_2SiO_3 wood adhesive by using the appropriate curing agent, skeleton material, or filler in order to make it suitable for wood adhesion.

The curing agent is an essential component of adhesive which can instantly react with the subject binder to produce a tough and durable three-dimensional network structure by altering the capabilities of curing glue. The quantity of curing agent also affects the mechanical strength of the curing adhesive and its ability to bond to wood.

In an aqueous solution of sodium silicate, it hydrolyzes into silicic acid, which then gradually dries and solidifies. For this work, the Na_2SiO_3 wood adhesive's curing agent and film forming substance is Silica gel G. Silica gel G can be defined as a coherent, rigid three-dimensional network of contiguous particles of colloid silica, which can be prepared by the polymerization of silicic acid or by the aggregation of particles of colloidal silica.[30] It enhances the production of silicic acid in water-glass solutions. The curing reaction equations are as follows:

$$Na_2O.nSiO_2 + (2n+1)\ H_2O \longrightarrow 2NaOH + nSi(OH)_4$$
$$Na_2O.nSiO_2 + 2n\ H_2O + CO_2 \longrightarrow Na_2CO_3 + nSi(OH)_4$$
$$2SiO_2 + 4H_2O \longrightarrow 2Si(OH)_4$$

The above product, $Si(OH)_4$, can form multi-polysilicic acid by auto-agglutination. Multi-polysilicic acid generates a -Si-O-Si-chain network structure, which is then dehydrated and condensed to create the inorganic film.

Besides this, silica gel G also contains 13% of Calcium sulfate, which forms gypsum after hydration. When semi-hydrate gypsum in the saturated solution reacts with water, it transforms into dihydrate gypsum. Because the solubility of dihydrate gypsum is substantially lower than that of semi-hydrate gypsum, the saturated solution of semi-hydrate gypsum is oversaturated for dihydrate gypsum. As a result, the saturated solution precipitates dihydrate gypsum in the form of colloid particles, causing the semi-hydrate gypsum to dissolve and hydrate continuously until total dissolution. Because of hydration and evaporation, the free water in the adhesive mixture steadily decreases throughout this process, and the colloid particles of dihydrate gypsum grow. It is a fast process therefore additionally increasing curing process and strength of the silicate adhesive. [31-32]

$$CaSO_4 + 1/2H_2O \longrightarrow CaSO_4.1/2H_2O$$

$$CaSO_4.1/2H_2O \longrightarrow CaSO_4.2H_2O$$

Effect of gum arabic: Gum arabic (GA) is a natural polymer that is made up of polysaccharide and glycoprotein which gives it the properties of a glue and binder, having high water solubility and biocompatibility at a cheap cost. It is an ingredient of glazing mixture. The gum is made up of a combination of calcium, magnesium, and potassium salts of Arabic acid, a complex branching polysaccharide including galactose, glycuronic acid, arabinose, and rhamnose residues. It is quickly biodegradable hence non-hazardous material. Gum Arabic is hydrophilic and possesses branching polymeric structures therefore it is very easily intermixed with sodium silicate and provide good cohesion and adhesion to sodium silicate.[33-35]

Water resistance property: Moisture absorption experiment was performed to investigate the effect of gum arabic on water resistance property of sodium silicate. Water absorption property has an inverse relationship with water resistance. At various time intervals—3, 6, 9, 12, 18, 21 and 24 hours—the water absorption rates of pure sodium silicate, modified sodium silicate by silica gel G, and modified sodium silicate with various quantities of gum arabic were measured. After three hours, SS has a 2.68% water absorption rate; however, after becoming slowly dissolved in the water, this rate drops to 2.60%. Due to its water soluble nature, it fully disintegrated over time into the water; as a result, teak wood blocks joined by SS were completely separated after 6 to 9 hours of water immersion.

However, even after being submerged in water for 24 hours, modified sodium silicate joined with silica gel G and modified sodium silicate joined with various amounts of gum arabic did not separate. It was evident that each type of adhesive's rate of water absorption increased over time. It was discovered that modified sodium silicate with 6% gum arabic demonstrated a lower water absorption rate than its other compositions.

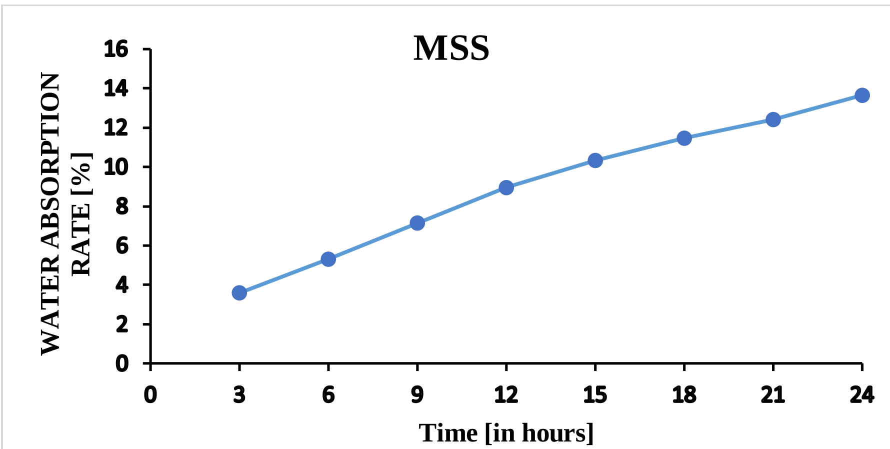

Figure 4: Water absorption rate of modified Sodium silicate (MSS).

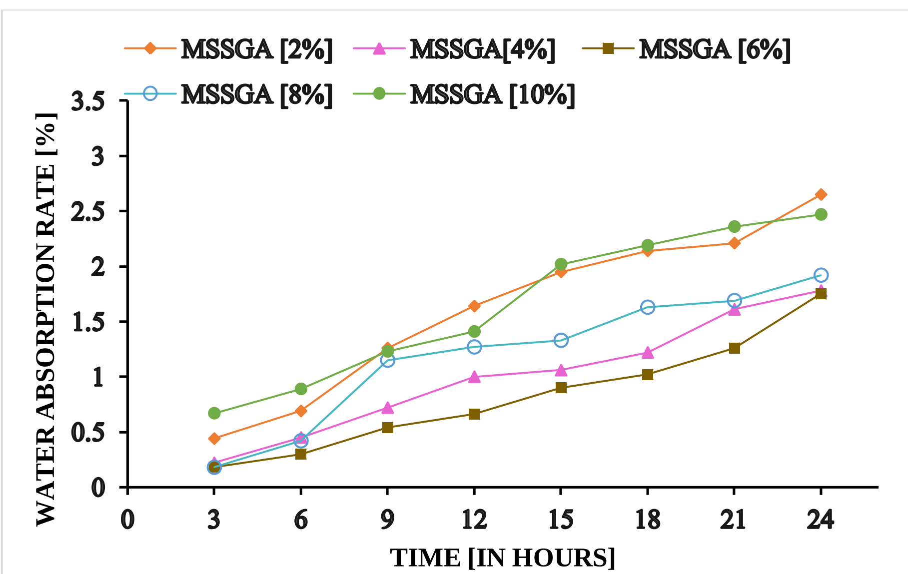

Figure 5: Water absorption rate of modified Sodium silicate by using different % of gum arabic (MSSGA).

- **Tensile strength:** The results of tensile strength investigations of pure sodium silicate and modified sodium silicate without and with gum arabic are shown in Fig 5. It was found that tensile strength of 3.87 MPa is the minimum for simple sodium silicate wood adhesive, while tensile strength increased to 7.90 MPa for modified sodium silicate. The bonding strength of the adhesive increased first and then decreased as the gum arabic content in the Na_2SiO_3 solution increased from 2% to 10%. Compared with Na_2SiO_3 wood adhesive without gum arabic, the bonding strength of the adhesive with 4% of gum arabic adhesive was increased from 3.87 MPa to 10.06 MPa, as shown in Figure 6.

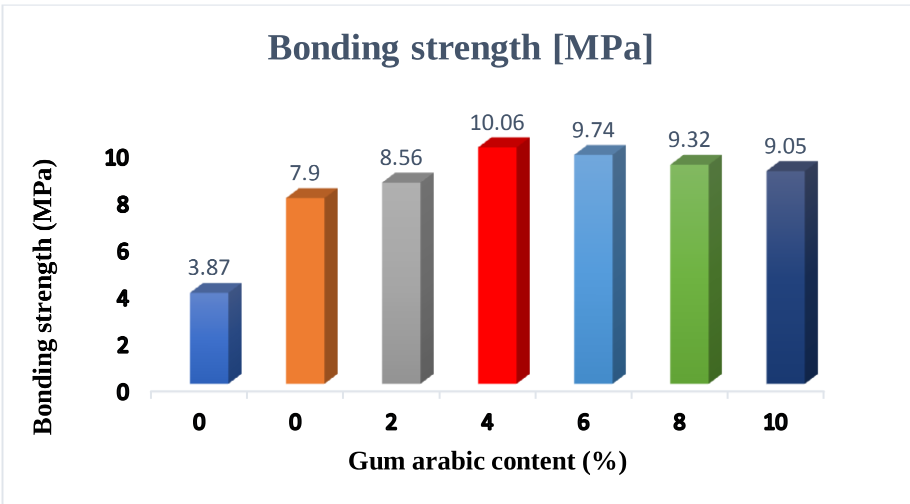

Fig.6 Tensile strength of SS, MSS & MSSGA (2 % - 10%).

On the other hand, the curves of experimental tensile stress with tensile strain extension of SS, MSS and MSSGA of 2-10% gum arabic shown in Figure 7. It is predicted that highest tensile stress was found at maximum tensile strength (4% MSSGA).

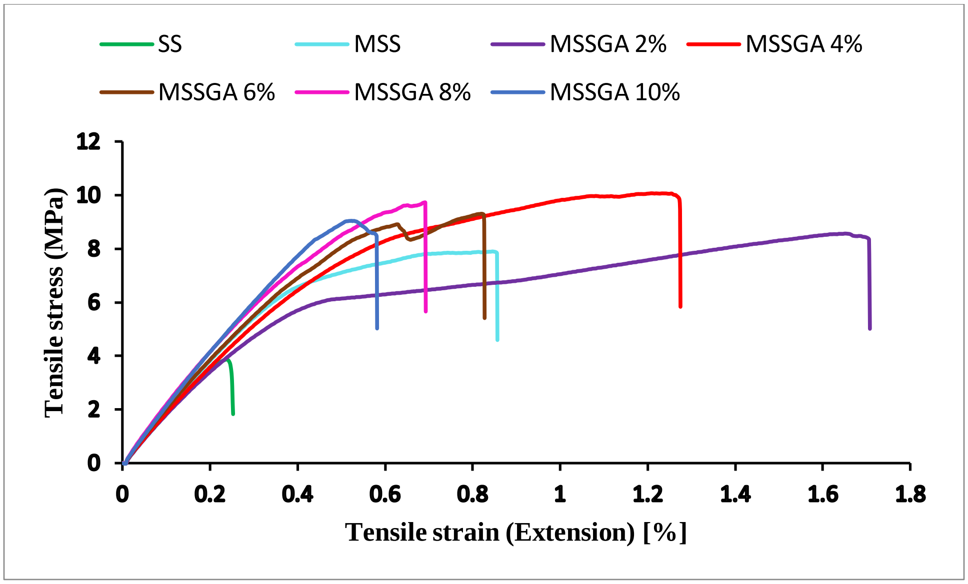

Figure 7: Tensile stress Vs Tensile strain (extension) for wood joint specimen by using SS, MSS and different types of MSSGA.

Bonding strength Vs 24 hours water absorption rate: MSS (7.90 MPa, 13.64%) has superior bonding strength and a 24 hour water absorption rate than SS (3.87 MPa, separated). When the amount of gum arabic (2–10%) in the modified Na_2SiO_3 solution was increased, both the bonding strength and the 24-hour water absorption rate initially increased and later decreased. The maximum bonding strength (10.06 MPa) is achieved when the gum arabic content in MSSGA is 4%, while the 24-hour water absorption rate was 1.78%.Gum arabic dose of 6% resulted in a bonding strength of 9.74 MPa and a minimum 24 hour water absorption rate of 1.75%.The bonding strength decreased as the gum arabic level increased, and the rate of water absorption after 24 hours increased as well, showing that too much gum arabic was harmful to adhesion. The findings demonstrated that the addition of silica gel curing agent and gum arabic additive into the Na_2SiO_3 adhesive greatly increased bonding strength and 24 hour water absorption rate. Additionally, based on the findings of the study, the ideal formulation of modified sodium silicate with gum arabic adhesive should consist of 80 ml of water glass, 20 g of silica gel, and 4-6% gum arabic of the weight of the modified Na_2SiO_3 solution in order to achieve good adhesive qualities. Figure 8 represent the findings.

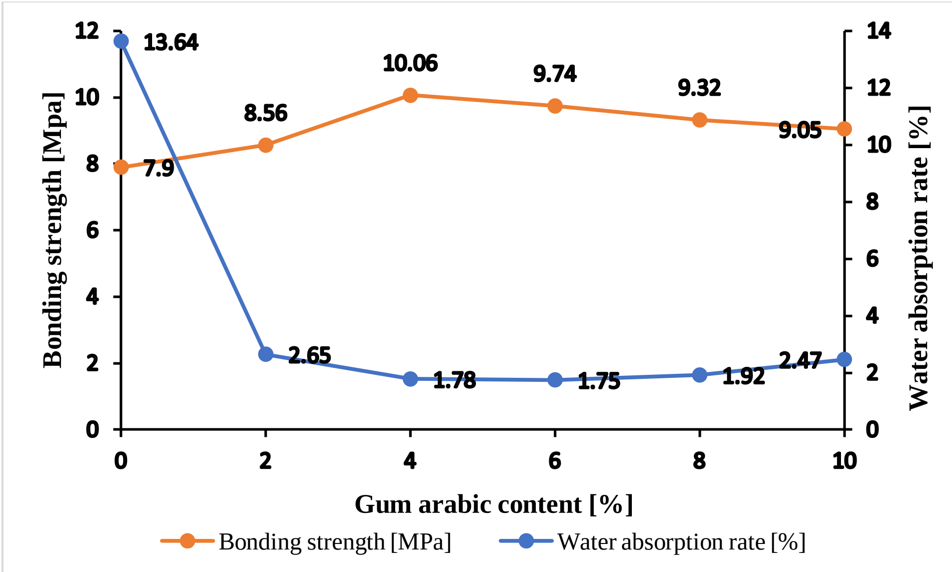

Figure 8: Bonding strength and 24 h water absorption rate of MSS and MSSGA (with different % of gum arabic)

FT-IR analysis: Figure 9 displayed the combined FT-IR spectra of the SS, MSS, and 4% MSSGA samples. Si-OH stretching vibration band in SS had a large stretching absorption peak at 3257.25 cm^{-1}. After the modification, this peak was diminished as a result of the Si-OH being used up in the formation of Si-O-Si bonds. This showed that adding silica gel G and gum arabic encourage the formation of Si-O-Si bonds.

In MSSGA, at 2886.17cm^{-1}, a small peak of the -CH_2- stretching vibration band is easily detectable. At 2326.15 cm^{-1}, the SS clearly showed the CO_2 absorption peaks. Additionally, in MSSGA, the stretching and bending vibrations peaks of the Si-O bond were seen at 1642.47 cm^{-1} and 980.23 cm^{-1}, respectively. The fact that the MSSGA adhesive's bending vibration peak area of Si-O-Si is slightly larger than that of the other two spectra suggests that the gum arabic's various functional groups react with Si-OH to create a larger network of Si-O-Si bonds, increasing the adhesive's tensile strength.

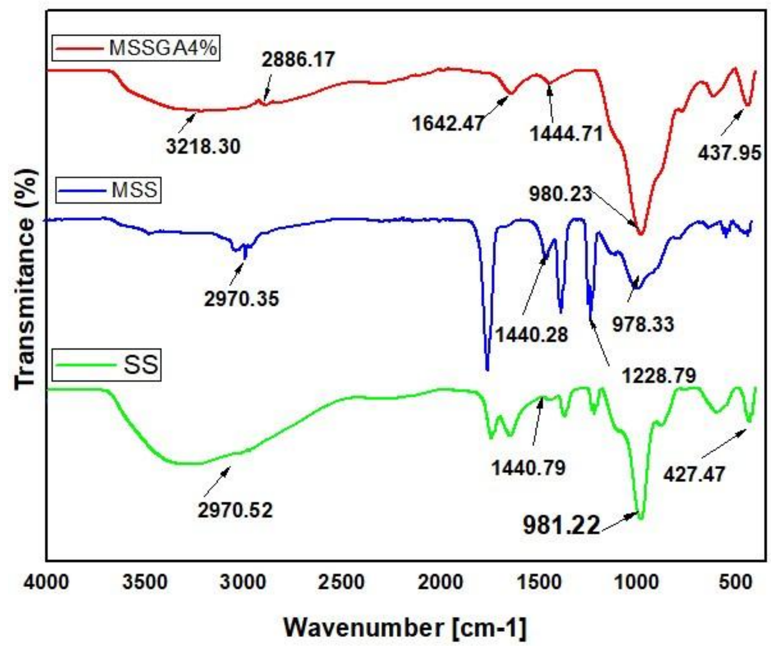

Figure 9: FT-IR spectra of SS, MSS & 4% MSSGA

The surface layer of the finished adhesive had undergone the following chemical reaction during curing, as evidenced by the strong distinctive peak of carbonate that formed at 1440.79 cm^{-1} in SS and 1444.70 cm^{-1} in MSSGA.

$$Na_2O.mSiO_2.nH_2O + CO_2 \longrightarrow Na_2CO_3 + mSi(OH)_4.nH_2O$$

In MSSGA a medium sharp peak appeared at 1228.79 cm^{-1} indicated that a portion of free hydroxyl groups bonded with SS react with gum arabic and form Si-O-C bond.

Si-O-Si vibrational peaks were observed at 981.22 cm^{-1} and 427.47 cm^{-1} in SS. In contrast to SS & MSS, the vibration peak of Si-O was noticeably stronger in MSSGA at 980.23 cm^{-1}, showing that the combination of chemicals (MSSGA) can further promote the curing of adhesive to improve its bonding strength.

These peaks' appearance suggested that gum arabic with silica gel G had a chemical interaction with silicate glue and had been successfully incorporated into the adhesive material.

TGA analysis: The TGA results, as shown in Figure 10, confirmed the stronger molecular structure of modified sodium silicate wood adhesive and modified sodium silicate with 4% gum arabic wood adhesive. Modified sodium silicate and modified sodium silicate wood adhesive with gum arabic both experience total weight losses of 30.74% and 22.31%, compared to simple sodium silicate wood glue, which experiences a total weight loss of 77.99%. It explains that modified sodium silicate with gum arabic wood adhesive has a thermal stability that is 8.43% more high than MSS.

It is also observable that in the investigated temperature range (27^0C to 800^0C), modified sodium silicate wood adhesive—both with and without gum arabic—has greater thermal stability than simple sodium silicate.

The thermal stability of adhesive at high temperatures supports its strong bonding and water resistance, indicating that sodium silicate, silica gel, and gum arabic formed a more cross-linked network structure, giving the modified adhesive better thermal stability and a wider temperature range for use.

.

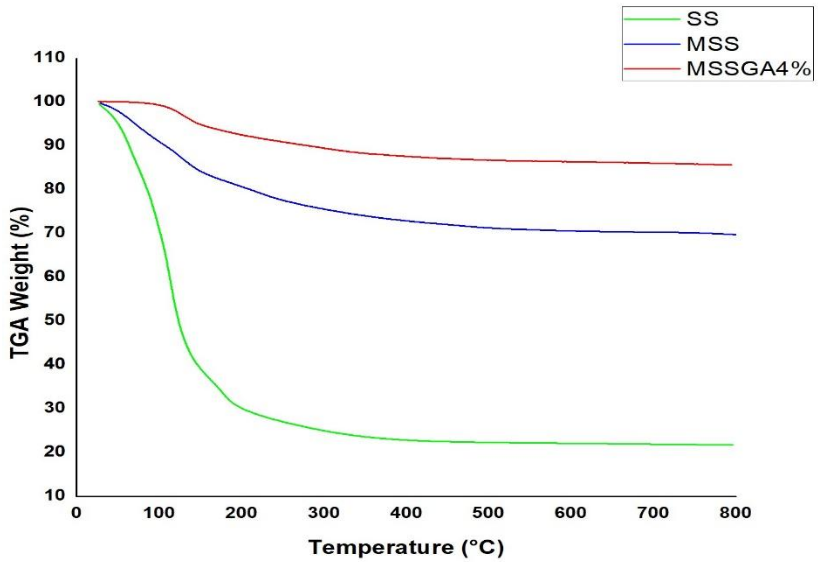

Figure 10: TGA curves of SS, MSS & 4% MSSGA

CONCLUSION

- In comparison to the SS adhesive, the bonding strength and water resistance of MSS & MSSGA were both enhanced, with the water resistance being raised in particular, meeting the purpose of modification. The enhanced molecular structure and heat stability of the modified Na_2SiO_3 adhesive contributed to its performance improvement.
- The 24-hour water absorption rate in SS fails after 6 to 9 hours, resulting in the separation of blocks in simple Sodium silicate, while in MSS teak wood blocks were joined even after 24 hours of water immersions. MSS have 13.64% of 24 h water absorption rate than SS, and wood blocks were still jointed and MSSGA with 6% gum arabic of the weight of modified Na_2SiO_3 solution with silica gel G was found to have minimum 24 h water absorption rate that is 1.75%, which improved water resistance by 87.17% in comparison to MSS.
- The bonding strength of MSS improved by 104.13% than SS and compared to MSS, the maximum bonding strength of MSSGA with 4% gum arabic of the weight of modified Na_2SiO_3 solution with silica gel G improved by 27.34%.
- Compared to MSS, the bonding strength and water resistance properties of MSSGA improved by 27.34% and 87.17%, respectively.
- On the basis of above results it is concluded that bonding strength and water resistance of SS have been significantly improved by adding gum arabic in modified Na_2SiO_3 adhesive containing 20% silica gel G and to obtain good adhesive properties, the optimized

formula of modified sodium silicate with gum arabic adhesive should be 80 g of water glass, 20 g of silica gel, and 4%-6% gum arabic of the weight of modified Na_2SiO_3 solution.

References:

1. Pizzi, A. and Mittal, K. L. 2003. Handbook of adhesive technology, revised and expanded. CRC Press. https://doi.org/10.1201/9780203912225
2. Chen, T., Wu, Z., Wang, X. A., Wang, W., Huang, D., Wei, Q., Wu, B., and Xie, Y. 2018. Hierarchical lamellar Aluminophosphate materials with porosity as ecofriendly inorganic adhesive for wood-based boards. *ACS Sustain. Chem. Eng.*, 6, 6273−6280.
3. Liu, H., Feng, Y., Cao, X., Luo, B. and Liu, M. 2021. Chitin nanocrystals as an eco-friendly and strong anisotropic adhesive. *ACS Appl. Mater. Interfaces*, 13, 11356−11368.
4. Sun, W., Tajvidi, M., Hunt, C. G., McIntyre, G. and Gardner, D. J. 2019. Fully bio-based hybrid composites made of wood, fungal mycelium and cellulose nanofibrils. *Sci. Rep.*, 9(1), 3766.
5. Marques, A., Mocanu, A., Tomić, N., Balos, S., Stammen, E., Lundevall, A., Abrahami, S., Günther, R., de Kok, J., and Teixeira de Freitas, S. 2020. Review on adhesives and surface treatments for structural applications: Recent developments on sustainability and implementation for metal and composite substrates. *Materials*, 13(24), 5590. https://doi.org/10.3390/ma13245590
6. Li, H.P. 2009. Formulation technology manual of adhesive. Beijing: Chemical Industry Press, 1st ed., pp. 831.
7. Cai. Y. 1997. Synthesis of melamine-formaldehyde resin modified poly (VAc-MMA) emulsion. *China Adhes.*, 2, 43–45.
8. Chen. Y. 1996. Researches of wood adhesives with high strength, water and creep resistance. *Nianjie*, 1, 25–7.
9. Huang, M., Kuo, S. Wu, H., Chang, F. and Fang, S. 2002. Miscibility and hydrogen bonding in blends of poly (vinyl acetate) with phenolic resin. *Polymer*, 8, 2479–2487.
10. Kim, S. and Kim H.J. 2005. Effect of addition of polyvinyl acetate to melamine-formaldehyde resin on the adhesion and formaldehyde emission in engineered flooring. *Int. J. Adhes. Adhes.*, 25, 456–461.
11. Voitovich V.A. 2010. Curing Agents of Silicate Based Adhesives. *Polym. Sci., Ser. D.* Glues and Sealing Materials, 3(3), 174–176. https://doi.org/10.1134/s1995421210030032
12. Rasauli, M.I. 2022. A study on the influence of sodium silicate concentration and SiO_2 : Na_2O ratio on the properties of low calcium fly ash based alkali activated materials cured at ambient conditions. *Adv. Mater. Sci. Eng.*, 2022, 1-7. https://doi.org/10.1155/2022/7762507
13. Furness, R. 1922. Sodium silicate as an adhesive. *J. Soc. Chem. Ind.*, 41(18), 381 R -384 R. https://doi.org/10.1002/jctb.5000411801

14. Bianche, J.J., Carneiro, A. D. O., Vital, B. R., Andrade, B.G.D., Gomes, R.M Araújo, S.D.O. and De Souza, E.C. 2022. Improving the understanding of wood bonding: Behavior of different adhesives on the surface of eucalyptus and pine wood. *Int. J. Adhes. Adhes.,* 112,102987. https://doi.org/10.1016/j.ijadhadh.2021.102987.
15. Pizzi, A. and Salvado, J. 2007. Lignin-based wood panel adhesives without formaldehyde. *Eur J. Wood Wood Prod.,* 65(1), 65-70.
16. Tognonvi, M.T., Rossignol, S. and Bonnet, J.P. 2011. Physical-chemistry of sodium silicate gelation in an alkaline medium. *J Sol-Gel Sci. Technol.,* 58, 625-635.
17. Qiangqiang L., Haojia D. U., Wenhua L. (2021). Physical and Mechanical Properties of Poplar Wood Modified by Glucose-Urea-Melamine Resin/Sodium Silicate Compound. *Forests*, 12.(2), 127,2021.https:// doi:10.3390/f12020127
18. Zhang, X., Liu, X., Yang, S., Long, K., and Wu, Y. 2012. Effect of carboxyl methyl cellulose on the adhesion properties of sodium silicate wood adhesive. *Proceedings of 2012 International Conference on Biobase Material Science and Engineering.,* 230-233. doi:10.1109/bmse.2012.6466218
19. Suleman, Y. H. and E. M. S. Hamid, E.M.S. 1997. Chemically modified soluble sodium silicate as an adhesive for solid wood panels, *J. Wood Res. Soc.,* 43, 855.
20. Zhang, X. L., Wu, Y. Q., Yang, S. L. and Liu, X. M. 2014. Effect of curing technology on bonding properties of silicate wood adhesive. *Mater. Res. Innov.,* 18(S2), S2-532–S2-536. doi:10.1179/1432891714z.000000000478
21. Zhang, X. L., Zhang, H. H., Wu, Y. Q., and Hu, Y. C. 2014. Preparation and Characterization of Silicate Wood Adhesive Modified with Ammonium Stearate. *Adv. Mater. Res., 1033-1034, 1048–1053.* doi:10.4028/www.scientific.net/amr.1033-1034.1048
22. Zhang X.L., Wu Y.Q. and Hu Y.C. 2012. Research on the properties of nanoparticles modified sodium silicate adhesive. *Adv. Mater. Res.,* 557-559, 1825-1829. doi:10.4028/www.scientific.net/AMR.557-559.1825.
23. Neyses, B., Rautkari, L., Yamamoto, A. and Sandberg, D. 2017. Pre-treatment with sodium silicate, sodium hydroxide, ionic liquids or methacrylate resin to reduce the set-recovery and increase the hardness of surface-densified Scots pine. *IForest*, 10, 857-864. doi: 10.3832/ifor2385-010
24. Yucheng P., Yousoo H. and Douglas G.J. 2012. Southern pine impregnated with silicate solution containing cellulose nanofibrils, *Holzforschung*, 66(6), 735-737. doi:10.1515/hf-2011-0128
25. Cheumani, Y., Žigon, A.M., Ngueteukamlo, J., A., Pavliˇc, M., Dahle, S., Petriˇc, M. 2021. Preparation, Surface Characterization, and Water Resistance of Silicate and Sol-Silicate Inorganic–Organic Hybrid Dispersion Coatings for Wood. *Materials*, 14, 3559. https://doi.org/10.3390/ ma14133559
26. IS 11215: 1991.Moisture content of timber and timber products- Methods for determination [CED 9: Timber and Timber Stores]

27. IS 1708-1 to 18 (1986): Methods of testing of small clear specimens of timber [CED 9: Timber and Timber Stores].
28. IS 848 (2006): Specification for Synthetic Resin Adhesives for Plywood (Phenolic and Aminoplastic) - [CED 20: Wood and other Lignocellulosic products].
29. IS 851 (1978): Specification for Synthetic Resin Adhesives for Construction Work (Non-Structural) in Wood [CED 20: Wood and other Lignocellulosic products].
30. Valdes, S. T. and Fuertes A.B. 2006. High surface area inorganic compounds prepared by nanocasting techniques, *Mater. Res. Bull.*, 41(12), 2187-2197. https://doi.org/10.1016/j.materresbull.2006.04.018]
31. Zhang, H. 2011. Air hardening binding materials, building materials in civil engineering, Woodhead publishing, 29-423, ISBN 9781845699550. https://doi.org/10.1533/9781845699567.29.
32. Li, Y., Duan, P. X., Miao, Y. C., and Li, Q. 2014. Preparation of α high-strength gypsum from FGD gypsum by autoclaved semi-dry process. *Adv. Mater. Res.*, *1051*, 230-236. https://doi.org/10.4028/www.scientific.net/amr.1051.230
33. Ocheri, C., Agboola, J.B. and Moses, O.M. 2017. Investigation of gum arabic and its suitability as a composite binder for core production. *J. powder metall. min.*, 6(1), 1000147. doi:10.4172/2168-9806.1000147
34. Elblbesy, M. A., Hanafy, T. A., and Shawki, M. M. 2022. Polyvinyl alcohol/gum Arabic hydrogel preparation and cytotoxicity for wound healing improvement. *e-Polymers*, 22(1), 566-576. https://doi.org/10.1515/epoly-2022-0052
35. Ali, B.H., Ziada, A., Blunden G. 2009. Biological effects of gum arabic: a review of some recent research. *Food Chem. Toxicol.*, 47 (1), 1-8. doi:10.1016/j.fct.2008.07.001. PMID 18672018.