Effect of Guar Gum on Tensile Strength and Moisture Resistance Properties of Sodium Silicate as Wood Adhesive

Choudhary Manju[1], Pal Bhupendra[2] and Meenakshi[1]*
1. Department of Chemistry, University of Rajasthan, Jaipur, Rajasthan, INDIA
2. Government Polytechnic college, Karauli, Rajasthan, INDIA
*meenakshialwaraj@gmail.com

Abstract
Sodium silicate has excellent binding qualities and has potential uses in a variety of areas due to its non-toxic, odor-free and fire proof properties. It is very cheap and volatile organic compound free from other available harmful organic adhesive materials. In spite of a lot of positive points, low water resistance has limited its usage as an adhesive in the wood industry on a wide scale. To enhance the bonding properties of sodium silicate for teak wood, three sets of sodium silicate adhesive (simple sodium silicate, modified sodium silicate with silica gel G and guar gum with modified sodium silicate) were prepared.

The results showed that modified sodium silicate with 6% guar gum works best for tensile strength as well as best for water resistance. Results of FT-IR data and SEM showed that guar gum was successfully introduced in silicate structure, having good thermal stability in the range of 27^0C-800^0C supported by TGA results.

Keywords: Sodium silicate, guar gum, water resistance, tensile strength, etc.

Introduction

Adhesives are substances used to unite the surfaces of various materials. They have the ability to firmly attach to surfaces. These days, the wood industry uses a lot of petrochemical-derived organic adhesives. These adhesives including urea-formaldehyde resin, phenolic resin, melamine formaldehyde resin and others have great bonding qualities like high bonding strength and good water resistance, but the majority of organic adhesives also contain volatile organic compounds that are harmful to human health and environment.

Environmentally friendly adhesives will eventually take place of organic adhesives as a result of the developing global energy crisis and rising environmental awareness. Inorganic adhesives are low-cost, non-burning, eco-friendly materials that are compatible with the present organic adhesive sector[3,17]. Inorganic adhesives have gained more and more attention in recent years.

Among all available inorganic adhesives, silicate adhesives, particularly sodium silicate, are the most promising. Sodium silicate, often known as water glass, has many ideal features such as being rich in natural resources, having high adhesion performance and being easy to handle.[1,2,4,9,19] It is non explosive, non- toxic and non-flammable.

The adhesive made of sodium silicate is free of volatile organic compounds, has low adhesive stress, good temperature resistance, strong bonding strength and is difficult to burn. The industries of metal, ceramic, glass, stone and wood all can use it for binding. Since sodium silicate is hygroscopic, its practical applicability as a wood adhesive is limited[11,18]. Its glue line is brittle and inelastic. Many of these issues limited its application in the wood sector against organic adhesives.

Zhang[22] studied the effect of curing technology on bonding properties of silicate wood adhesive. Yucheng et al[21] studied the research on silicate solution with cellulose nanofibrils effect on Southern pine. Zhang et al[23-25] studied the properties of nanoparticles modified sodium silicate adhesive.

Neyses et al[13] 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. Zhang et al[23] studied the properties of sodium silicate adhesive using carboxymethylcellulose (CMC) additive. Yona et al[20] studied the research with sodium silicate and sol-silicate inorganic-organic hybrid dispersion coating preparation, surface coating and water resistance on wood. Qiangqiang et al[14] investigated the physical and mechanical properties of sodium silicate compound with glucose-urea-melamine resin modification on poplar wood. Zhang et al[25] studied the effect of ammonium stearate on bonding properties of sodium silicate.

According to the findings of the literature analysis, it might be possible to modify sodium silicate to produce high-performance adhesive. This study examines how adding guar gum as an additive and silica gel G as a curing agent can improve the qualities of an adhesive. The bonding strength and water resistance of the Na_2SiO_3 adhesive were evaluated in order to assess its adhesion capabilities. The interaction between Na_2SiO_3, silica gel G and guar gum in the adhesive structure was investigated and it was discovered that the cured morphology and thermal characteristics support the claim that addition of guar gum improved the quality of Na_2SiO_3 as wood adhesive.

Material and Methods

Materials: For adhesive work, 52^0 Be translucent sodium silicate solution is suitable. It was collected from O.P. Industry, Jaipur, Rajasthan, India. The chemical analysis of sodium silicate is: Na_2O =13.65%, SiO_2 = 33.66%, Specific gravity =1.54, Viscosity = 1553.23 mPa.s, weight ratio SiO_2/Na_2O = 2.47:1, pH = 11.70, total solid = 26%.

In the present research work, guar gum was used as an additive. It was collected from general shop, Jaipur. Silica gel G with 13% $CaSO_4$ was collected from chemical store of Department of Chemistry, University of Rajasthan, Jaipur. *Tectona grandis* (teak) wood was obtained from the Balaji Timber Industry, Jaipur.

Preparation of wood samples: In accordance with IS 11215[6] and IS 1708,[5] wood samples with dimensions of 150 mm x 25 mm x 3 mm and a moisture content of 13% were prepared.

Preparation of modified Sodium silicate adhesive: A beaker was initially filled with 80 ml of water glass and then 20 g of silica gel G was added. After thoroughly stirring the mixture, modified sodium silicate adhesive was produced.

Preparation of modified Sodium silicate adhesive with guar gum: Five clean, dry beakers were taken and sample numbers 1 to 5 were assigned. Sodium silicate with curing agent (80 ml of water glass and 20 g silica gel G) was put in bowls no. 1 to 5. Then 2, 4, 6, 8 and 10 g of guar gum powder were added to beaker no. 1 to 5 respectively. The prepared modified sodium silicate adhesives with different percentages of guar gum are shown in fig. 1. The samples of experiment are described in table 1.

Moisture resistance investigation: Teak wood blocks were glued using a double coating of simple sodium silicate (SS), modified sodium silicate with silica gel G (MSS) and modified sodium silicate containing various amounts of guar gum (MSSG), all of which were applied at pressures of 0.5-0.9 MPa at 30°C for 24 hours (Fig. 2). Then, by measuring the ratio of the difference in mass before and after 24 hours of immersion in water, water absorption rates with various time intervals were calculated according to Indian standards[7,8]. Moisture resistance is inversely proportional to water absorption. Figure 4 includes the outcomes.

Tensile strength investigation: Teak wood blocks were doubly glued with SS, MSS and MSSG containing guar gum 2% to 10% and were placed under pressures of 0.5-0.9 MPa at 30°C for 24 hours. After that these wood blocks were tested on an Instron-5967 Universal testing machine (Fig. 3). The outcomes are shown in fig. 5.

Fig. 1: Different samples of modified sodium silicate with guar gum (2% to 10%)

Fig. 2: Preparation of wood blocks for water resistance investigation

Table 1
The samples of experiments

Component	Sample number				
	S 1	**S 2**	**S 3**	**S 4**	**S 5**
Water glass(ml)	80	80	80	80	80
Silica gel (gm)	20	20	20	20	20
Guar gum (gm)	2	4	6	8	10

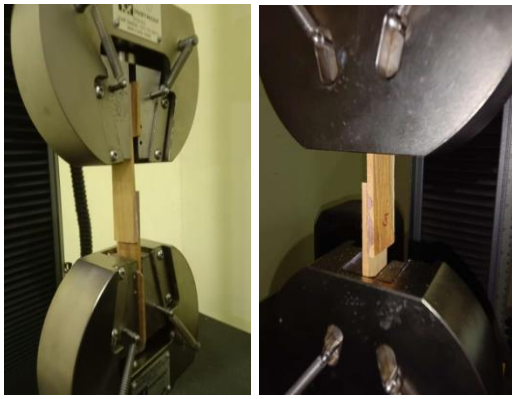

Fig. 3: Tensile strength testing of sodium silicate adhesive on wood blocks

The average findings of each experimental method were reported after being carried out six times.

Spectral analysis

1) **Fourier transform-infrared spectroscopy (FT-IR) analysis:** FT-IR spectra were obtained using an FT-IR Spectrum 2 (Perkin Elmer, Jaipur). ATR mode is used to study the sample. Each sample was scanned 32 times over a region of 4000-400 cm^{-1} at a resolution of 4 cm^{-1}.

2) **Scanning electron microscopy (SEM) analysis:** Surfaces of cured films of the adhesive samples were coated with gold under vacuum. Then all specimens were observed using SEM (MIRA3 TESCAN, Jaipur, India) under high vacuum mode.

3) **Thermogravimetric analysis (TGA):** Thermal stability of the adhesive samples was analyzed using a STA 6000 Perkin Elmer thermal analyzer, Jaipur (India). 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: After fully curing, a single component sodium silicate adhesive ($Na_2O.nSiO_2$**),** also known as water glass adhesive, transforms into a translucent, brittle substance. According to preliminary research, curing faults like stress cracks and bubbles in the binding line are simple to identify when used as wood adhesive. To produce Na_2SiO_3 wood adhesive acceptable for wood adhesion, the brittleness must be decreased by employing the proper curing agent, skeleton material, or filler. The curing agent, a crucial part of adhesive, can rapidly react with the target binder to create a sturdy three-dimensional network structure, changing the abilities of the curing glue. The quantity of curing agent also affects the mechanical strength of the curing adhesive and its ability to bond to wood. It hydrolyzes into silicic acid in an aqueous solution of sodium silicate, which then gradually dries and solidifies[24]. Silica gel G serves both as curing agent and a film-forming component for the Na_2SiO_3 wood adhesive in this work. It increases the amount of silicic acid that is produced in water-glass solutions[24,25] (eq. 1 to 3):

$$Na_2O.nSiO_2+(2n+1)H_2O \longrightarrow 2NaOH + nSi(OH)_4 \quad (1)$$
silicic acid

$$Na_2O.nSiO_2+2nH_2O+CO_2 \longrightarrow Na_2CO_3 + nSi(OH)_4 \quad (2)$$

$$2SiO_2+4H_2O \longrightarrow 2Si(OH)_4 \quad (3)$$
Silica gel silicic acid

By auto-agglutination, the aforementioned product, $Si(OH)_4$, can transform into multi-polysilicic acid. The -Si-O-Si-chain network structure produced by multi-polysilicic acid is dehydrated and condensed to produce the inorganic film. In addition to this, silica gel G contains a small quantity of calcium sulfate, which when hydrated becomes gypsum quickly, speeding up the curing process and enhancing the product's strength (eq. 4):[10]

$$CaSO_4 +2H_2O \longrightarrow CaSO_4.2H_2O \quad (4)$$
Gypsum

Effect of guar gum: Guar gum, commonly known as guaran, is derived from guar beans with excellent thickening and stabilizing qualities. Guar gum is an exo-polysaccharide comprised of the sugars galactose and mannose[18]. The backbone is a linear chain of 1,4-linked mannose residues to which galactose residues are 1,6-linked at every second mannose, generating small side-branches. Because of its additional galactose branch points, guar gum is more

soluble. It is nonionic and hydrocolloidal in water. It has good film formation properties and wide pH stability range[15].

Guar gum hydrates quickly and makes an extremely viscous solution. The quantity of free hydroxy groups allows for the creation of derivatives for specific uses. When guar gum is mixed with sodium silicate solution, it yields a complex mixture of polymerization between silicic acid (Si-OH) and–OH groups of guar gum and enhancing the formation of –Si-O-Si- network and three dimensional intercrossing structure between silicic acid and guar gum molecule in the adhesive and will promote curing and improve water resistance. Being harmless, very good thickner, binder and film forming substance[12], guar gum was used as an additive to modify the bonding performance of sodium silicate adhesive.

Water resistance property: The inverse relationship exists between water resistance and water absorption. The water absorption rates of pure sodium silicate, modified sodium silicate by silica gel G and modified sodium silicate with various concentrations of guar gum were measured at various time intervals (3, 6, 9, 12, 18, 21 and 24 hours). 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 totally disintegrated over time, therefore teak wood blocks joined by SS were completely separated between 6-9 hours of water immersion. Even after being submerged in water for 24 hours, modified sodium silicate combined with silica gel G and modified sodium silicate joined with various amounts of guar gum remained intact. 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% guar gum displayed a lower water absorption rate than other compositions when compared to additives with varying guar gum percentages.

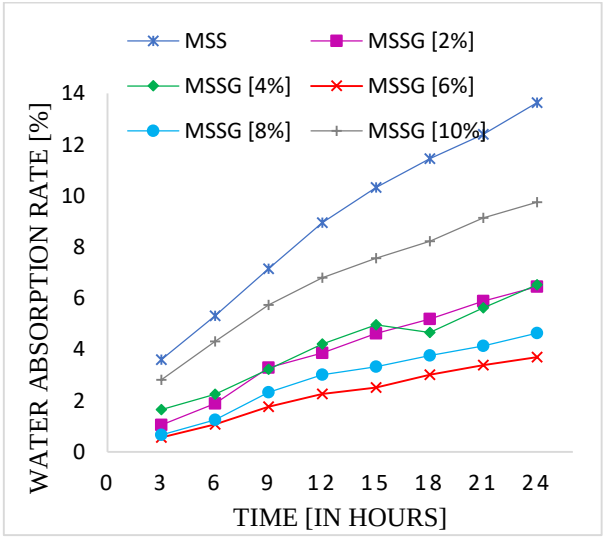

Fig. 4: Water absorption rate of modified Sodium silicate (MSS) and Modified Sodium silicate by using different % of guar gum (MSSG).

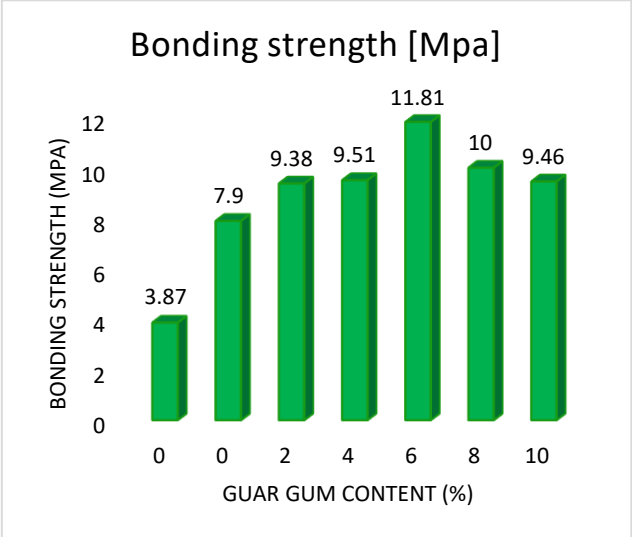

Fig. 5: Tensile strength of SS, MSS and MSSG (2 % to 10%).

Tensile strength: Figure 5 illustrates how well pure sodium silicate and modified sodium silicate adhere to surfaces both without and with guar gum. Tensile strength was found to be at a minimum of 3.87 MPa for simple sodium silicate wood glue and to rise to 7.90 MPa for modified sodium silicate. As the amount of guar gum in the Na_2SiO_3 solution became from 2% to 10%, the bonding strength of the adhesive first increased and then decreased. As demonstrated in fig. 5, the bonding strength of the adhesive with 6% of guar gum adhesive jumped from 3.87 MPa to 11.81 MPa when compared to Na_2SiO_3 wood adhesive without guar gum.

On the contrary, the experimental tensile stress with tensile strain extension curves for the SS, MSS and MSSG of 2-10% guar gum concentration suggested that the highest tensile stress was found at the maximum tensile strength (Fig. 6).

Bonding strength Vs 24 hours absorption rate: It is reported in fig. 7 that MSS (7.90 MPa, 13.64%) has superior bonding strength and 24 hour water absorption rate than SS (3.87 MPa, separated). When the amount of guar gum (2–10%) in the modified Na_2SiO_3 solution was increased, both the bonding strength and the rate of 24 hour water absorption initially increased and then decreased. When guar gum is 6% in MSSG, the bonding strength is at its highest (11.81 MPa), but the water absorption rate over 24 hours is at its lowest (3.7%). Guar gum was found to be detrimental to adhesion when the amount was too high as the bonding strength and 24-hour water absorption rate both increased as the guar gum concentration increased.

The results showed that curing agent silica gel and guar gum additive were added to the sodium silicate adhesive to greatly improve its bonding strength and 24 hour water absorption rate. According to the findings of research, the ideal formulation of modified sodium silicate with guar gum adhesive should consist of 80 ml of water glass, 20 g of silica gel and 6% guar gum by weight of the modified Na_2SiO_3 solution in order to achieve good adhesive qualities.

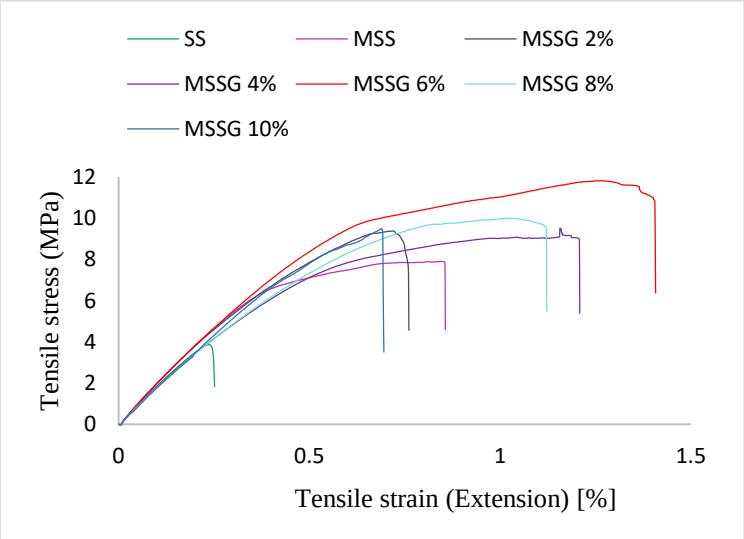

Fig. 6: Tensile strength versus Tensile strain (extension) for wood joint specimen by using SS, MSS and different types of MSSG

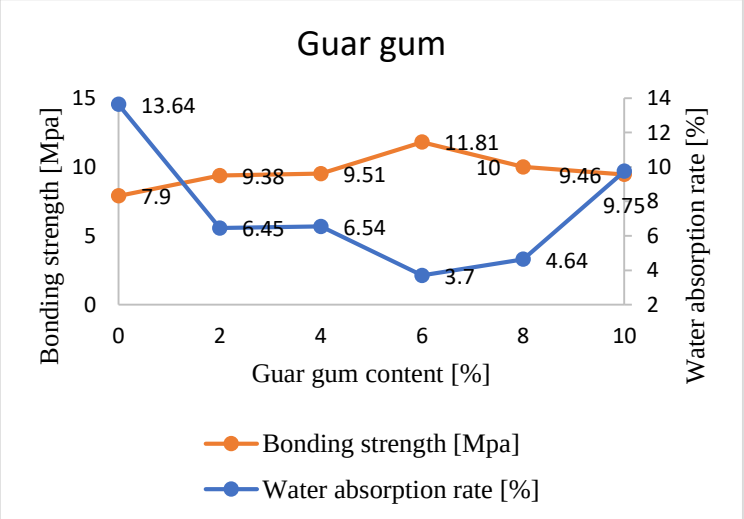

Fig. 7: Bonding strength and 24 h water absorption rate of MSS and MSSG (with different % of guar gum)

FT-IR analysis: Figure 8 displayed the combined FT-IR pattern of the SS, MSS and 6% MSSG 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 weakened as a result of the Si-OH being used up in the formation of Si-O-Si bonds. This implied that the addition of guar gum and silica gel would facilitate the formation of Si-O-Si bonds. At 2970.35 cm^{-1} in MSSG, a small peak of the -CH_2- stretching vibration band is clearly observable. The CO_2 absorption peaks were clearly visible at 2326.15 cm^{-1} and 2323.44 cm^{-1} in SS and MSSG respectively.

Additionally, in MSSG the stretching and bending vibrations of the Si-O bond were seen at the peaks at 1643.35 cm^{-1} and 976.12 cm^{-1} respectively. The fact that the MSSG adhesive's bending vibration peak area of Si-O-Si is slightly larger than that of the other two spectra, suggests that different functional groups of guar gum react with Si-OH to generate a larger network of Si-O-Si bonds, increasing the adhesive's strength. A strong characteristic peak of carbonate appeared at 1440.79 cm^{-1} in SS and 1442.14 cm^{-1} in MSSG (eq. 2).

A medium peak in MSSG that developed at 1216.96 cm^{-1} showed that certain free hydroxyl groups that were previously bound to SS were reacting with guar gum to generate Si-O-C bonds. Si-O-Si vibrational peaks in SS were observed at 981.22 cm^{-1} and 436.46 cm^{-1}. In contrast to SS and MSS, combined chemicals (MSSG) can further promote the curing of adhesive to improve its bonding strength. This can be observed by the vibration peak of Si-O being noticeably stronger in MSSG at 976.12 cm^{-1}. These peaks' appearance demonstrated that guar gum and silica gel G had a chemical reaction with silicate adhesive and that guar gum had been successfully added to the adhesive.

SEM analysis: The effect of guar gum on the adhesion structure was directly shown by the SEM pictures in fig. 9-11. The cured micrograph of SS was rough and full of cracks due to its friable nature. MSS was brittle, rough and some fragile cracks also appeared on the surface of the film due to 13% $CaSO_4$. MSSG had more dense, smooth and uniform cured surface than that of SS and MSS, which showed that the guar gum modified adhesive had good compatibility, film forming capacity and good flexibility among components, thus having better binding properties.

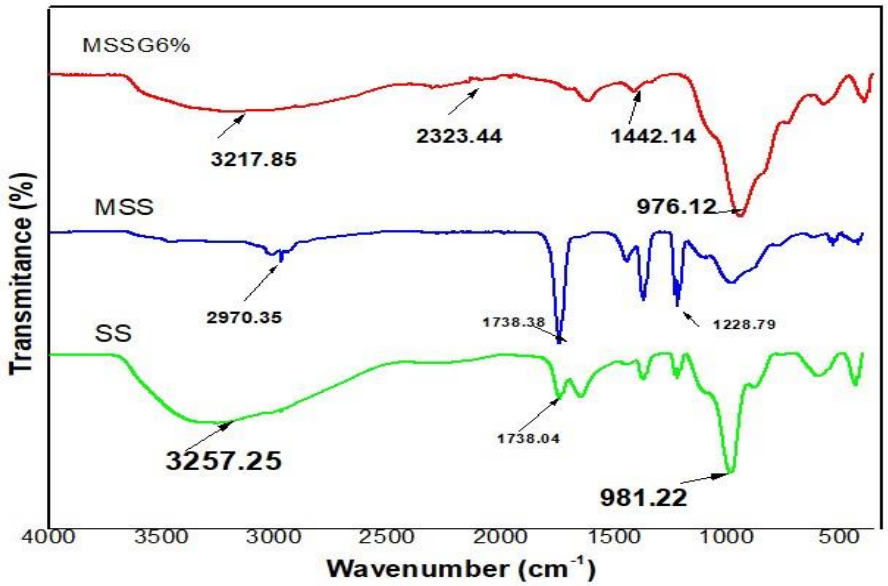

Fig. 8: FT-IR spectra of SS, MSS and 6% MSSG

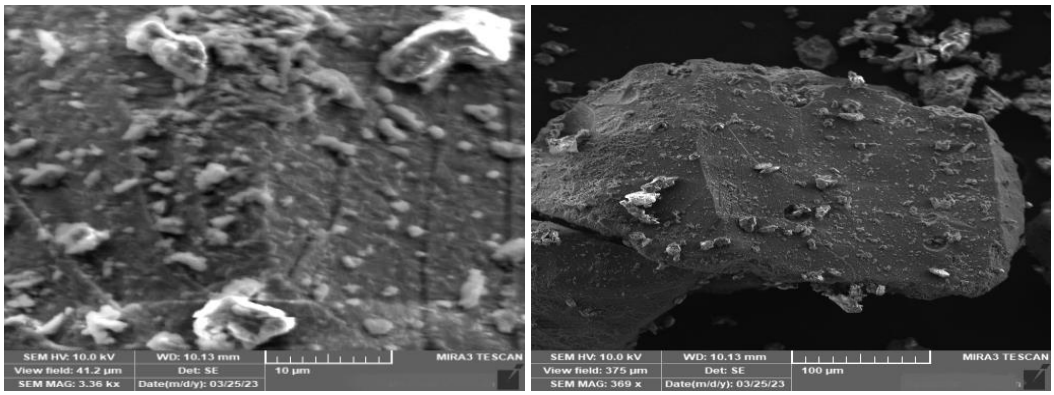

Fig. 9: SEM images of SS

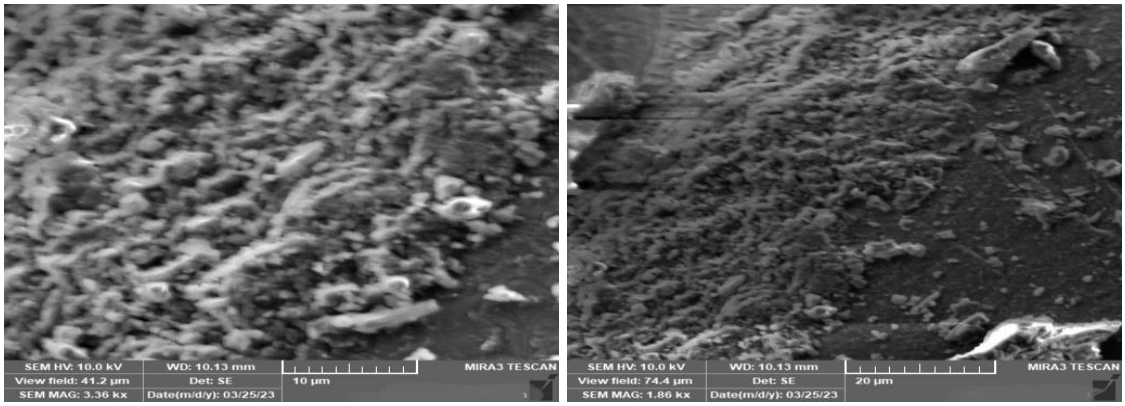

Fig. 10: SEM images of MSS

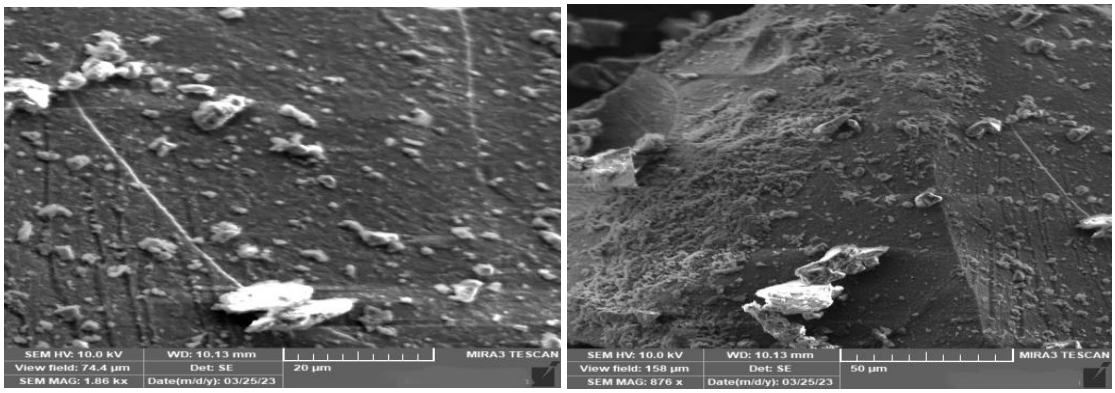

Fig. 11: SEM images of 6% MSSG

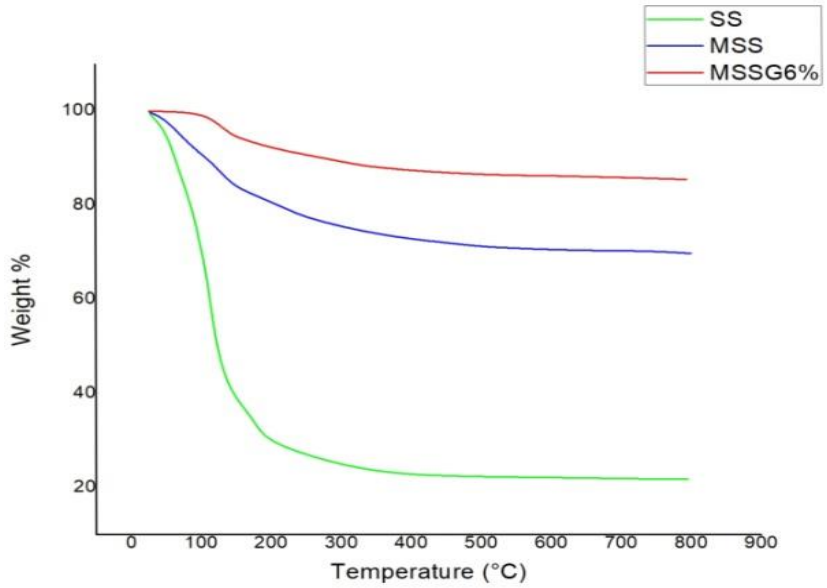

Fig. 12: Compiled TGA curves of SS, MSS and 6% MSSG

TGA analysis: The strengthened molecular structure of modified sodium silicate wood adhesive and modified sodium silicate with 6% guar gum wood adhesive was supported by the TGA results as shown in fig. 12. The total weight loss of modified sodium silicate and modified sodium silicate wood adhesive with guar gum is 30.74% and 14.52% respectively while the total weight loss is 77.99% for simple sodium silicate wood adhesive. It is clear that both MSS and MSSG are more thermally stable than SS. It explains that the thermal stability of modified sodium silicate is 16.22% lower than modified sodium silicate with guar gum wood adhesive.

It is also clear that MSSG (6% guar gum) has better thermal stability than MSS and SS in the studied temperature range. Sodium silicate, silica gel and guar gum formed a more cross-linked network structure, making the modified adhesive possess with better thermal stability and can be

used for a wider temperature range. The thermal stability of adhesive under high temperature supports its good bonding strength and water resistance.

Conclusion

- Compared to the SS adhesive, bonding strength and water resistance were both enhanced of MSS and MSSG, with the water resistance being raised in particular, attaining the desired alteration. The enhanced molecular structure and thermal stability of the modified Na_2SiO_3 adhesive aided the improvement in performance.
- In contrast to MSS, the 24-hour water absorption rate in SS failed after 6 to 9 hours, resulting in the separation of blocks. MSS has 13.64% of 24 h water absorption rate than SS and wood blocks were still jointed and MSSG with 6% guar gum of the weight of modified Na_2SiO_3 solution with silica gel G was found to have minimum 24 h water absorption rate 3.7% which improved water resistance by 72.87% than MSS.
- Compared to SS, the bonding strength of MSS improved by 104.13% and compared to MSS, the maximum bonding strength of MSSG with 6% guar gum of the weight of modified Na_2SiO_3 solution with silica gel G improved by 49.49%.
- Compared to MSS, the water resistance properties of 6% MSSG improved by 72.87%.
- The overall results showed that bonding strength and water resistance of SS have been significantly improved by incorporating guar gum in modified Na_2SiO_3 adhesive containing 20% silica gel G. Furthermore, according to the research results, to obtain good adhesive properties, the optimized formula of modified sodium silicate with guar gum adhesive should be 80 g of water glass, 20 g of silica gel and 6% guar gum of the weight of modified Na_2SiO_3 solution.

Acknowledgement

The authors are thankful to Department of Chemistry, University of Rajasthan, Jaipur, India for providing laboratory facilities.

References

1. Cai Y., Synthesis of melamine-formaldehyde resin modified poly (VAc-MMA) emulsion, *China Adhesives*, **2**, 43-5 **(1997)**

2. Chen Y., Researches of wood adhesives with high strength, water and creep resistance, *Nianjie*, **1**, 25-7 **(1996)**

3. Gu J.Y., Adhesive and coatings, China's Forestry Press, Beijing, China, 1st edition, 244-245 **(1999)**

4. Huang M., Kuo S., Wu H., Chang F. and Fang, S., Miscibility and hydrogen bonding in blends of poly (vinyl acetate) with phenolic resin, *Polymer*, **8**, 2479-2487 **(2002)**

5. IS 1708-1 to 18: Methods of testing of small clear specimens of timber [CED 9: Timber and Timber Stores] **(1986)**

6. IS 11215: Moisture content of timber and timber products-Methods for determination [CED 9: Timber and Timber Stores] **(1991)**

7. IS 851: Specification for synthetic resin adhesives for construction work (Non-Structural) in Wood [CED 20: Wood and other Lignocellulosic products] **(1978)**

8. IS 848: Specification for Synthetic Resin Adhesives for Plywood (Phenolic and Aminoplastic) - [CED 20: Wood and other Lignocellulosic products] **(2006)**

9. Kim S. and Kim H.J., Effect of addition of polyvinyl acetate to melamine-formaldehyde resin on the adhesion and formaldehyde emission in engineered flooring, *International Journal of Adhesion and Adhesives*, **25**, 456-461 **(2005)**

10. Li Y., Duan P.X., Miao Y.C. and Li Q., Preparation of α high-strength Gypsum from FGD gypsum by autoclaved semi-dry process, *Advanced Materials Research*, **1051**, 230–236 **(2014)**

11. Mansouri N.E.L., Pizzi A. and Salvado J., Lignin based wood panel adhesives without formaldehyde, *European Journal of Wood and Wood Products*, **65**, 65-70 **(2007)**

12. Mudgil D., Barak S. and Khatkar B.S., Guar gum: Processing, properties and food applications- A Review, *Journal of Food Science and Technology*, **51(3)**, 409-418 **(2014)**

13. Neyses B., Rautkari L., Yamamoto A. and Sandberg D., 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, *International Forum for Environment, Sustainability and Technology*, **10**, 857-864 **(2017)**

14. Qiangqiang L., Haojia D. and Wenhua L., Physical and mechanical properties of poplar wood modified by glucose-urea-melamine resin/sodium silicate compound, *Forests*, **12(2)**, 127 **(2021)**

15. Thombare N., Jha U., Mishra S. and Siddiqi M.Z., Guar gum as a promising starting material for diverse applications: A review, *International Journal of Biological Macromolecules*, **88**, 361-372 **(2016)**

16. Tognonvi M.T., Rossignol S. and Bonnet J.P., Physical-chemistry of sodium silicate gelation in an alkaline medium, *Journal of Sol-Gel Science and Technology*, **58(3),** 625-635 **(2011)**

17. Tong Z.L., The latest design manual of adhesive, Chemical Industry Press, Beijing, China, 1st edition, 251-254 **(2010)**

18. Tripathy S. and Das M.K., Guar gum: Present status and applications, *Journal of Pharmaceutical and Scientific Innovations*, **4(4)**, 24-28 **(2013)**

19. Voitovich V.A., Curing agents of silicate based adhesives, *Polymer Science, Series D. Glues and Sealing Materials*, **3(3)**, 174-176 **(2010)**

20. Yona A.M.C., Žigon J., Kamlo A.N., Pavliˇc M., Dahle S. and Petriˇc M., Preparation, surface characterization and water resistance of silicate and sol-silicate inorganic–organic hybrid dispersion coatings for wood, *Materials*, **14(13),** 3559 **(2021)**

21. Yucheng P., Yousoo H. and Douglas G.J., Southern pine impregnated with silicate solution containing cellulose nanofibrils, *Holzforschung*, **66(6)**, 735-737 **(2012)**

22. Zhang X.L., Effect of curing technology on bonding properties of silicate wood adhesive, *Materials Research Innovations*, **18(S2),** 532-536 **(2014)**

23. Zhang X.L., Liu X., Yang S., Long K. and Wu Y., 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 **(2012)**

24. Zhang X.L., Wu Y.Q. and Hu Y.C., Research on the properties of nanoparticles modified sodium silicate adhesive. *Advanced Materials Research*, **557-559**, 1825-1829 **(2012)**

25. Zhang X.L., Zhang H.H., Wu Y.Q. and Hu Y.C., Preparation and characterization of silicate wood adhesive modified with ammonium stearate, *Advanced Materials Research*, **1033-1034**, 1048-1053 **(2014)**.

(Received 17th May 2023, accepted 17th June 2023)