

Development and Performance Evaluation of Soy Adhesive

L. O. Abiodun¹ and I. L. Ahmed²

¹ Department of Mechanical Engineering, University of Ilorin, Ilorin, Nigeria

² Department of Materials and Metallurgical Engineering, University of Ilorin, Ilorin, Nigeria

omololamusaabiodun@yahoo.com, ahmed.ii@unilorin.edu.ng

Abstract

Presently, particleboards are mainly produced with wood particles and urea-formaldehyde (UF) resins. The emission of carcinogenic formaldehyde in the production and use of particleboard has generated an urgent need for development of a formaldehyde-free wood adhesive for particleboard production. The aim of this research is to develop and conduct performance evaluation of soy adhesive, a green alternative that is not harmful to human health (carcinogenic free). In this work, soy adhesive was produced from soya beans and applied as binder in the production of particle board from wood dust often considered as wastes. The adhesive was added to the wood dust at different mixing ratios (weight ratio) and sieve sizes. The composite produced were compacted by cold pressing and subsequently dried at room temperature and in the oven at temperature of 105°C. The particle boards produced were tested for the performance evaluation. Physical properties namely, density, water absorption (WA) and thickness swelling (TS), and mechanical properties including Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) were assessed as a function of mixing ratios according to the ASTM D-1037-99 standard. The water absorption and TS were measured after 24 hours of soaking in water. It was observed that density decreased with increase in the proportion of the sawdust in the ratio. Similarly, the MOE and MOR of the fabricated particle board decreased with increase in the amount of sawdust in the mix. However, the water absorption and TS increased with proportion of saw dust in the mixing ratio.

Keywords

Particle board, sawdust, soy adhesives, physical properties and mechanical properties

1 Introduction

Increasing attention is been paid to the production and use of “green” adhesives for the manufacture and production of wood products. Interest in these bio-based adhesives has risen due to the health effects relating to the emissions of volatile organic chemicals (VOCs), especially formaldehyde. This pollution can be a long-term and may not be easier to handle.

Phenol-formaldehyde and urea-formaldehyde are the major petroleum-based formaldehyde and wood adhesives that are mostly used and readily available in the market (Li, 2012). These adhesives possess high glue strength and high water resistance, formaldehyde is reputed for excellent performance as it forms intra and intermolecular linkages within protein and nucleic acid upon absorption at the site of contact. However, this reputation comes with a significant risks to the health and safety of its users.

The formaldehyde released from wood composites is considered poisonous and toxic to human. These endanger the lives of workers and users of the wood composite. Typically, when its concentration in air is near to $120 \mu\text{g}/\text{m}^3$, formaldehyde causes various symptoms such as eye irritation, nose and throat irritation, headaches and skin rash (Liteplo, 2003). Increased risk of nasopharyngeal cancer up to 5.5 fold were observed among workers with 10-25 years of exposure to formaldehyde (West, 1993). Therefore, International Agency for Research on cancer, a division of WHO has since classified formaldehyde as a human carcinogen (Najafi, 2007). Again, the petrochemical-based adhesives are costly and non-renewable, hence constitute significant threat to the environment (Liu, 2010). Therefore, the development of environmental-friendly adhesive from renewable agricultural resources became necessary and has since awakened significant interest. Among many of the renewable resources, vegetable protein in which soy protein is an example, has been found to be better applicable raw material for wood adhesive. Soy adhesives are natural replacement for formaldehyde and phenol-based resins. It is a non-volatile, non-hazardous air pollutant, non-toxic and also a renewable solution to a long-standing environmental health issue (Liu, 2010).

2 Materials and Methods

2.1 Materials

The sawdust used for this study was collected from a saw mill in Ilorin where it is being regarded to as a waste and burnt. The soya beans used for the production of the adhesive were bought from a local market in Ilorin, Kwara state.

2.2 Experimental Methods

The sawdust were sun dried and sieved using sieve sizes of 0.8mm,1.7mm and 2.360 mm. 100g of sawdust was placed on the sieve and shaken continuously using mechanical shaker machine. This process was repeated for all the sawdust gathered for the research. The adhesives to sawdust ratios were at 90:10%, 80:20%, 70:30% and 60:40% by weight.

Table 1: Size distribution of collected sawdust

Particle size(mm)	Weight (%)
0.8	36.0
1.7	34.0
2.3	19.6
Others	10.4

2.3 Soy adhesive preparation

The soya beans were cleaned by removing every impurity, after which it was soaked in water for 4 hours to allow the soya beans to become soft for grinding. After grinding, it was sieved with a muslin cloth, because the sieve opening is small and hence produces fine sieved particles. The fine sieved solution was then cooked until the water is evaporated, and became thicker and sticky as shown in Figure 1.

2.4 Particle board preparation

The particle boards were made from sawdust of Melina wood. The dried sawdust was added to the adhesives in different mixing ratios namely: 90:10, 80:20. 70:30 and 60:40.The adhesive and sawdust in various mixing ratio were uniformly mixed, and then evenly distributed into a mould of 80mm × 150mm × 20mm and rammed. The rammed mould was then subjected to cold pressing with a load of 50N. The boards formed were allowed to dry at room temperature and then subsequently oven dried at 105°C. The sample

materials were then cut into 20mm ×150mm ×20mm each in order to determine the properties of the board.



Figure 1: Soaked Soyabeans (a) Grinded Soya (b), Sieving of Soya beans (c), Cooking of Soya beans (d) and (e) soy adhesive

2.5 Performance Evaluation of composite properties

Experimental tests were carried out according to the ASTM standard D-1037-99 (ASTM D-1037-99, 1999), for performance evaluation of the composite produced. Physical and mechanical properties tests were carried out.

2.5.1 Physical properties

2.5.1.1 Density

The board density for all the samples produced was determined from board samples of 20mm x 150mm x 20mm using the Equation 1

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} \quad (1)$$

2.5.1.2 Water soaking properties

Water absorption (WA) and thickness swelling (TS) were measured according to ASTM standard method D1037-99 (ASTM D-1037-99, 1999; Chen, 2006). The samples were soaked in water for 24 (ASTM D-1037-99, 1999) hours. The weight and thickness of board were measured before and immediately after soaking in water for 24 hours, the water absorptions and thickness swelling were measured (Najafi, 2007). Water absorption and thickness swelling of the specimens were calculated as percentage. The water absorption and thickness swelling were calculated according to the Equation 2 and 3 respectively:

$$WA(\%) = \frac{M_2 - M_1}{M_1} \times 100 \quad (2)$$

Where M_1 is the weight (g) of the specimen before soaking and M_2 is the weight (g) of the specimen after soaking.

$$TS(\%) = \frac{A_2 - A_1}{A_1} \times 100 \quad (3)$$

Where, A_1 is the thickness before soaking, and A_2 is the thickness after soaking.

2.5.2 Mechanical properties

The particle boards were cut into rectangular sections for determination of modulus of elasticity (MOE) and modulus of rupture (MOR). The dimensions of the specimen used for the mechanical tests were

150 mm × 20 mm x20mm. The MOE and MOR were obtained by following the three point flexural test using universal testing machine S300CT according to the ASTM D 1037–99 standard.

3 Results and discussion

3.1 Physical properties

3.1.1 Density

The most important indicator of composite’s performance is density, which basically affects all the properties of composites(Chen, 2006). It was observed, that density of composites showed decreasing trend with increase in the proportion of sawdust in the mixing ratio. The lowest density (250 kg/m³) was found in composites made with a mixing ratio of 60:40 of 1.7mm particle size, whereas the excessively higher density (667.0 kg/m³) corresponding to the ratio was 90:10 of 0.8mm particle size (Figure 2) could only be attributed to experimental error. However, the general trend was still maintained. This result showed that the density of the composite was actually determined by that of the adhesive which has the higher mixing proportion.

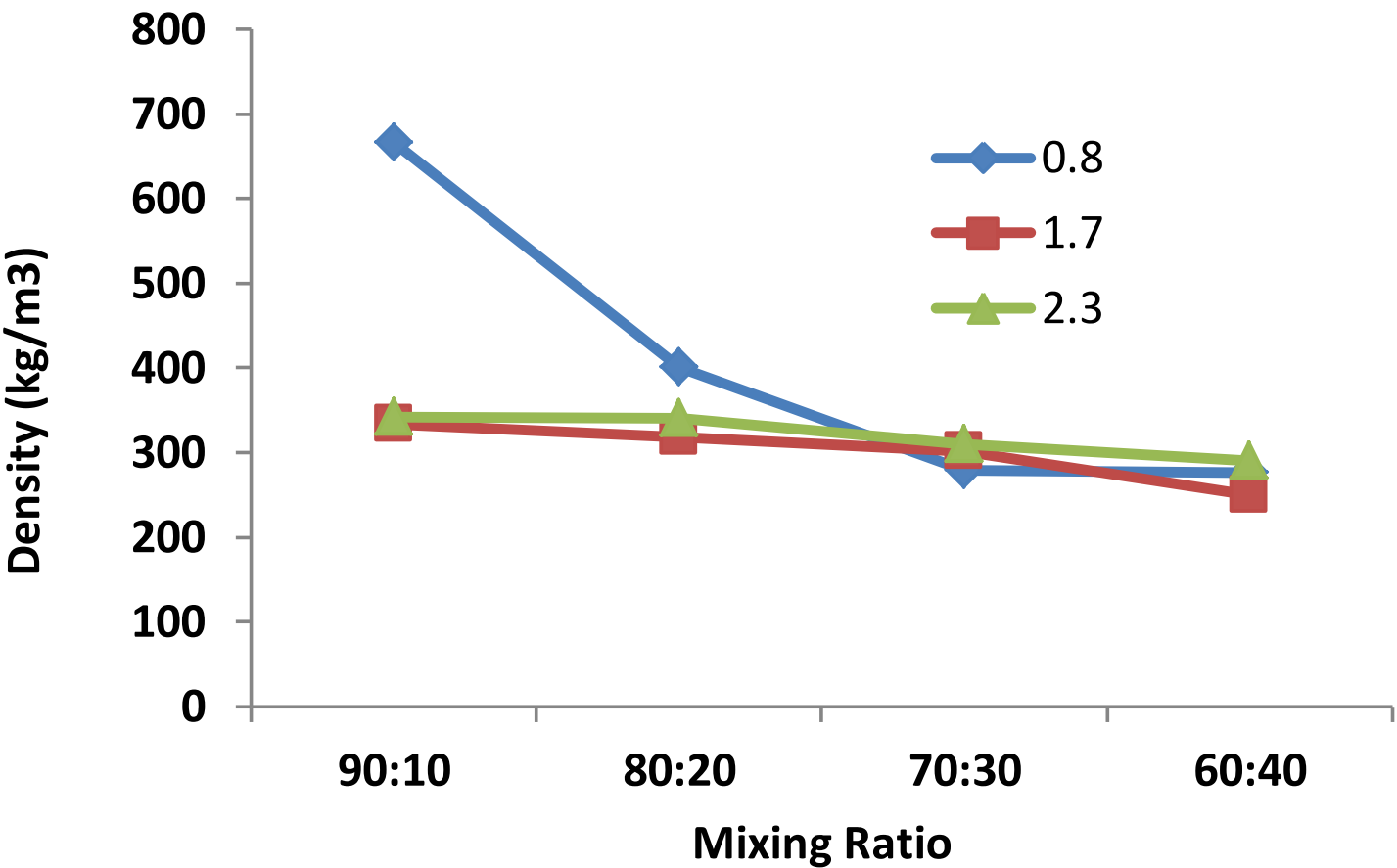


Figure 2 Density of composites at varying mixing ratio

Again, It could be suggested that the smaller wood particles of sawdust makes thinner mat and the compaction ratio would be higher resulting in better densification compare with larger particle sizes composite materials(Chen, 2006).This might be a reason for the higher density of

smaller particle size composite found in this study, aside the possible experimental error.

3.1.2 Water absorption

Water absorption of the composites based on various mixing ratio and different particle sizes (0.8, 1.7 and 2.3mm) after 24 hours of immersion in water are illustrated in Figure 3. Water absorption of the composites increased with the increase of sawdust content in the mixing ratio. The results of WAs were 225.96, 267.6 and 272.3% for 0.8, 1.7 and 2.3mm particle sizes, respectively with 40% sawdust content. The trend of WA results was attributed to the hydrophilic nature of wood. Wood is a hydrophilic porous composite which consists of cellulose, lignin and hemicelluloses polymers that are rich in functional groups such as hydroxyls, which readily interact with water molecules by hydrogen bonding and due to this reason, the composite have the ability to absorb water on exposure to wet and humid conditions (Adhikary, 2008). The increasing trend of WA result is consistent with the results of Chen (2006) on WPCs made from HDPE and recycled wood particles.

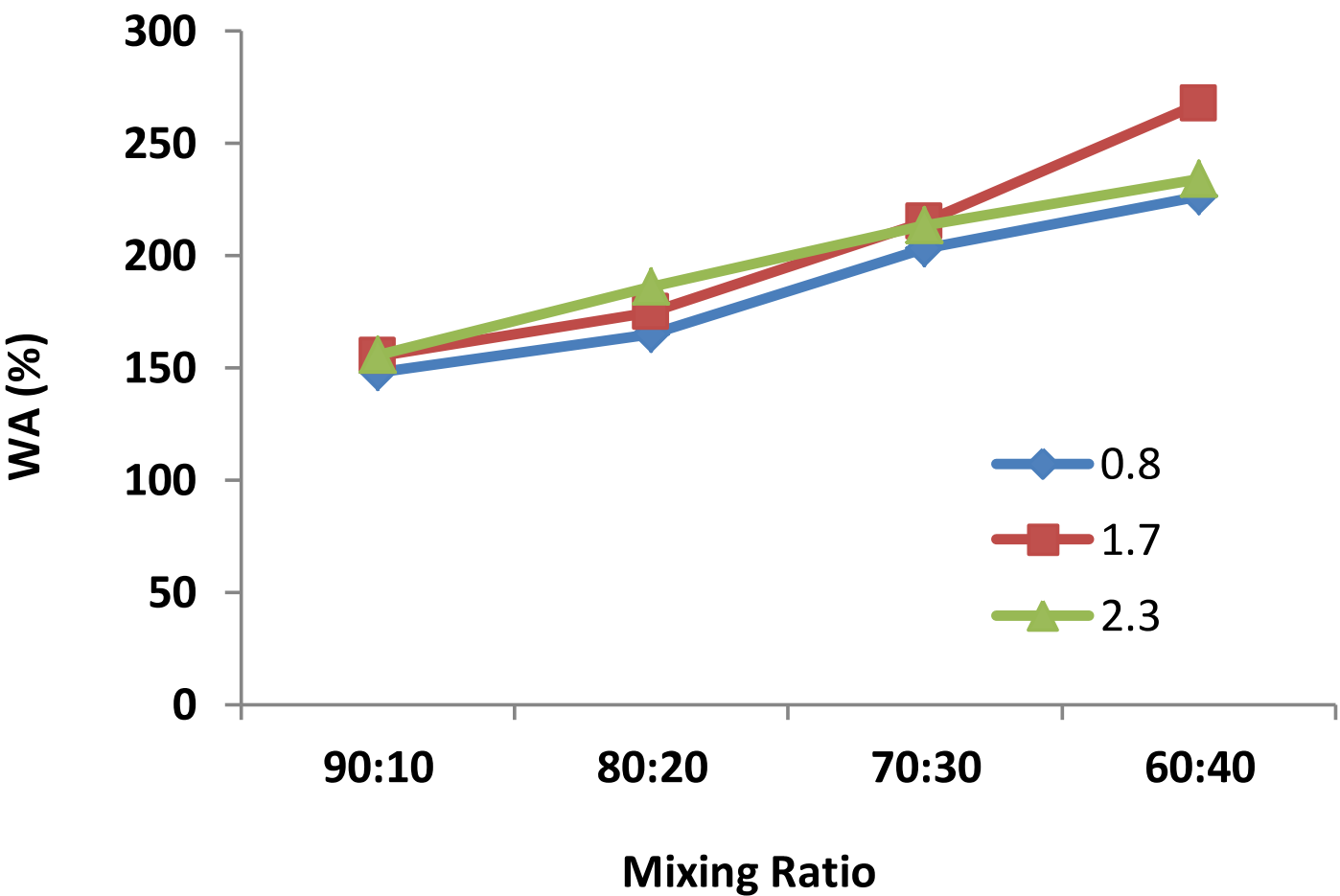


Figure 3 Water absorption of composites at varying mixing ratio. The reverse was for composites having lower sawdust content. On the other hand, higher water absorption of composites with the increasing soy adhesive content can be attributed to the hydrophilic character of the adhesive.

3.1.3 Thickness swelling

The result of thickness swelling was similar to that of Water absorption (see Figure 4). The result showed that the composites having lower percentage of adhesive were more susceptible to the thickness swelling than those of panels having higher adhesive content. This might be due to the increasing sawdust content in the mixing ratio which obviously has greater affinity for water absorption. This observation is in line with the report(Ayrilmis, 2011), thatwood fibres were mainly responsible for thickness swelling and water absorption of WPCs. The lowest thickness swelling was found for 90:10 mixing ratio of 0.8mm particle size while the highest was at mixing ratio of 60:40 of particle size 2.3mm. The increasing trend of TS results was similar to the results of TS reported by (Chen, 2006)for the thermoplastic composites made from HDPE and recycled wood particles.

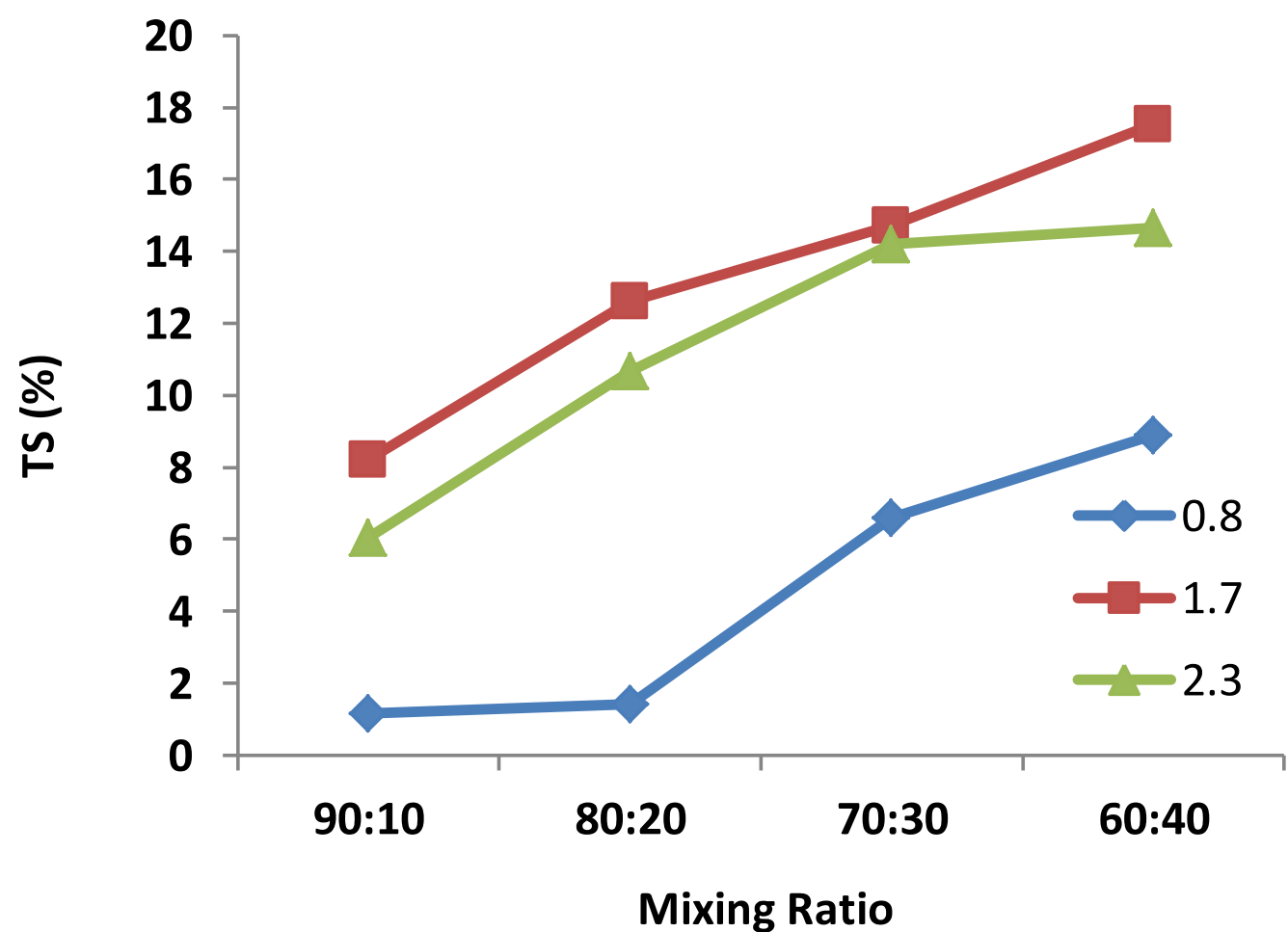


Figure 4Thickness swelling of composites at varying mixing ratio.

3.2 Mechanical properties

3.2.1 Modulus of elasticity

The MOE of composites decreased with higher sawdust in the mix (Figure 5). This variation might be due to the poor interfacial interaction between the sawdust and the adhesive, which hampers efficient stress transfer between the

two phases of the material. Though, the modulus of the natural fibres are found (Shibata, 2002) to be higher than the polymeric materials, yet the MOE of the composites could not fulfil the required standard of ANSI (1999) for both medium and low density particle board.

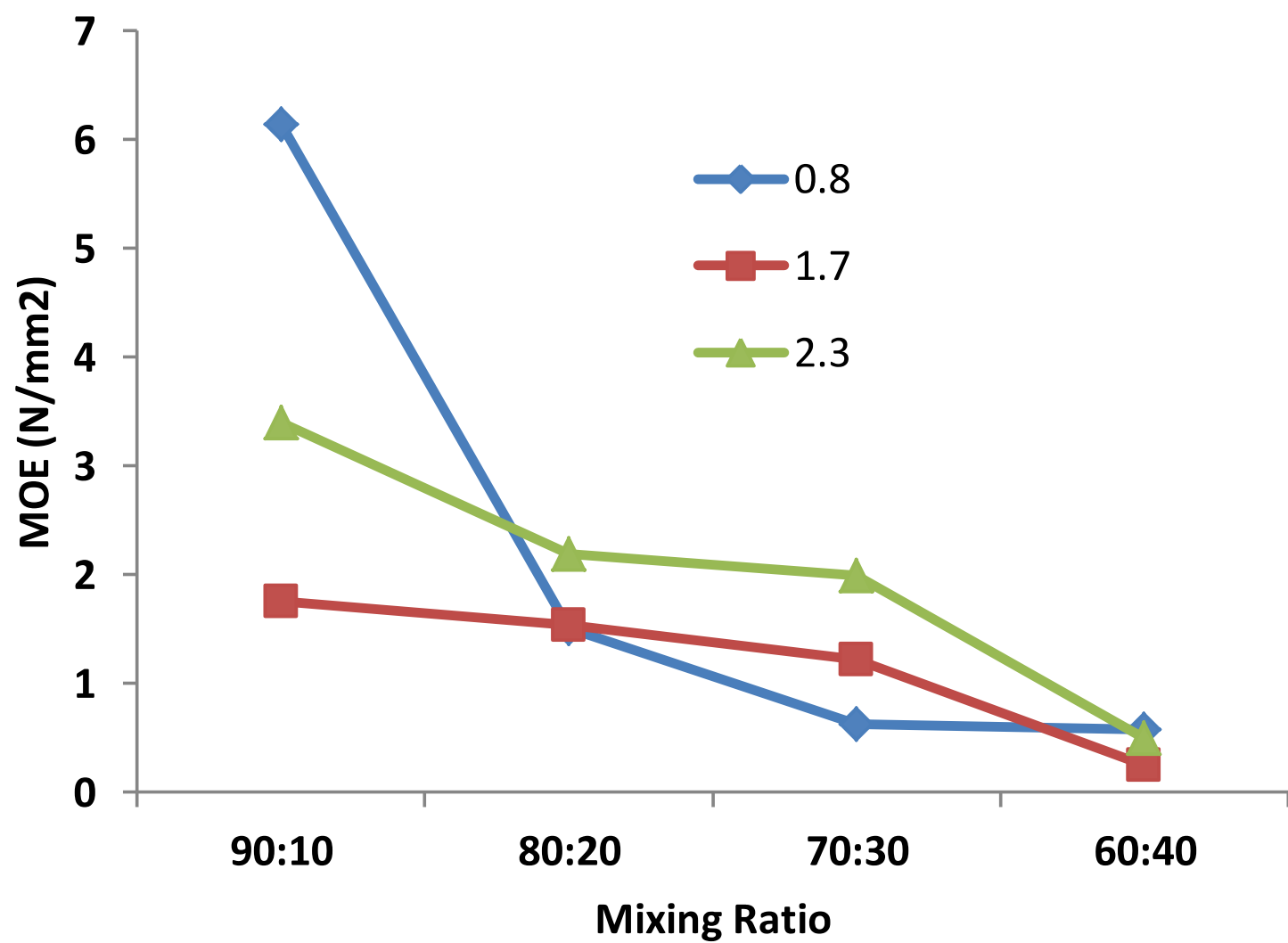


Figure 5 MOE of composites at varying mixing ratio.

3.2.2 Modulus of rupture

The effects of mixing ratio on the MOR of the composites are shown in Figure 6. The trend of the MOR was similar to the MOE. It was observed that the MOR of the composites decreased with the increase in the proportion of sawdust. The MOE ranged between 1305.19 and 93.74 N/mm². The decrease in the MOE of the composite with sawdust could be attributed to the gradual loss in the binding capacity of the soy adhesive with increasing amount of sawdust.

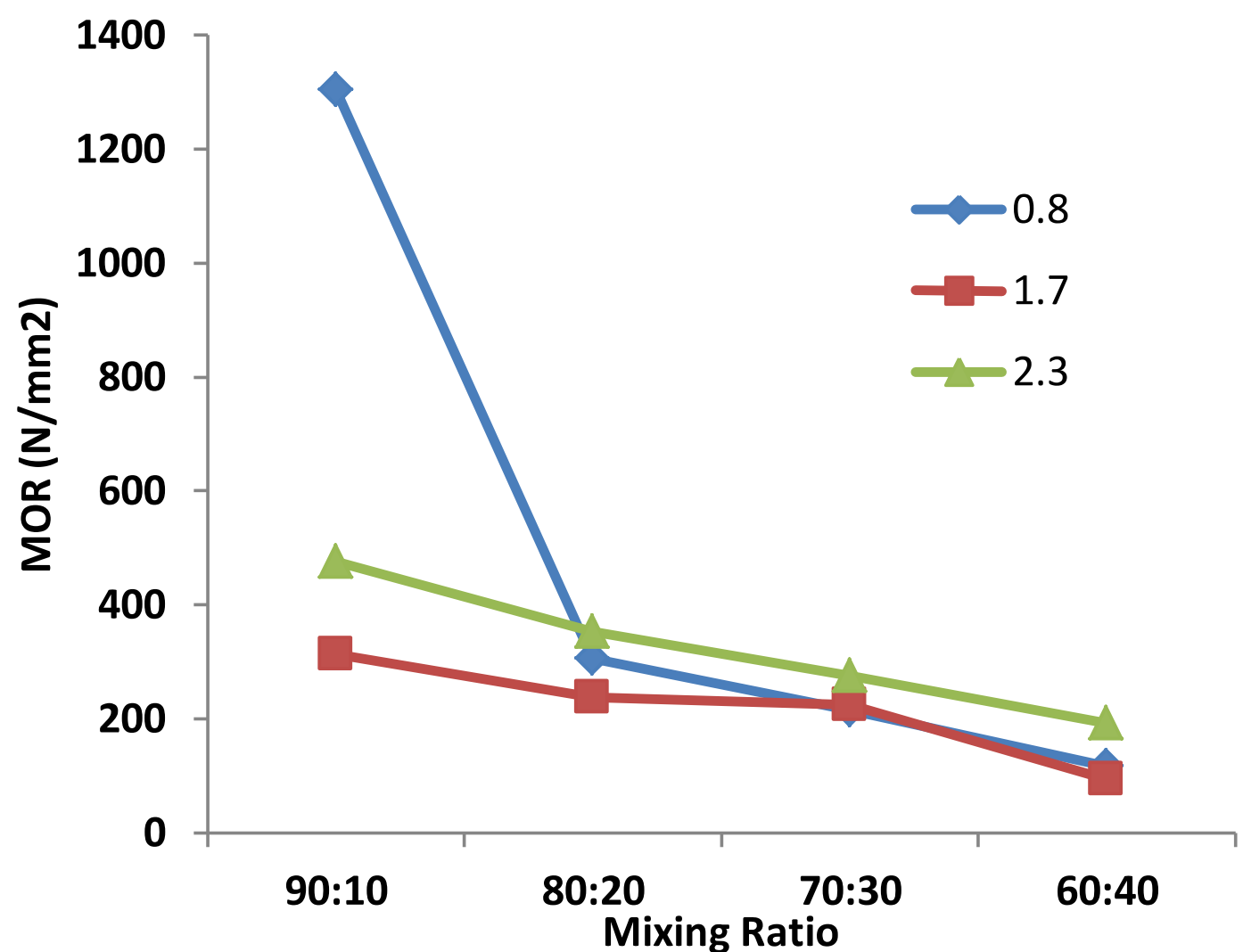


Figure 6 MOR of composites at varying mixing ratio

4 Conclusions

In this study soy adhesive was developed and tested at different mixing ratios of adhesive to sawdust. Therefore, from the above presented results and discussion, on the basis of physical and mechanical properties investigated, the following conclusions were drawn:

- 1. Wood particle size has a significant effect on the flexural strength of composite. The flexural strength of composite increases with the use of larger sized particles.
- 2. The water absorption, WA and thickness swelling, TS of larger wood particle size were adversely affected after soaking in water for 24 hours.
- 3. Higher content of adhesive in all the particle sizes used increases the density and flexural strength of composites but decreases the WA and TS.

References

Adhikary, K. B., Pang S, Staiger M P. (2008). Dimensional stability and mechanical behaviour of wood -plastic composites based on recycled and virgin high density polyethylene (HDPE). 39, 807-815.

ASTM D- 1037 -99. (1999). Standard Test Methods for Evaluating Properties of Wood- Base Fiber and Particle Panel Materials.

Ayrilmis, N., Jarusombuti S. (2011). Flat pressed wood plastic composite as an alternative to conventional wood based panel. *Journal of composite matter*, 45, 103-112.

Chen, H. C., Chen,T.Y., Hsu CH. (2006). Effect of wood particle size and mixing ratio of HDPE on properties of composites. *Holz Roh Werket*, 64.

Li, Q., Chen, N,Bian, L, Fan, M. (2012). Development of mechanism characterization of high performance soy-based adhesive. *International Journal of Adhesion and Adhesives*, 11-16.

Liteplo, R., Meek, M.E (2003). Inhaled Formaldehyde; Exposure estimation, Hazard characterization and Exposure response Analysis. *Journal of Toxicology and Environmental Health*, 85-114. doi: 10.1080/01694243.2012.696948

Liu, D., Chen,H,Chang,P.R,Wu,Q,Li,K,Guan,L. (2010). Biomimetic soy protein nanocomposite with calcium carbonate crystalline array for use as wood adhesive. *Bioresource Technology*, 6235-6241.

Najafi, S. K., Tajvidi M, Hamidina E. (2007). Effect of temperature, plastic type and virginity on water uptake of sawdust/ plastic composite. *Holz Roh Werket*, 65, 377-382.

Shibata, M., Takachiyo K, Ozuwa K, Yasomiya R, Takeishi H. (2002). Biodegradable polyester composite reinforced with short abaca fibre. *Journal of Applied Polymer Science*, 85, 129-138.

West, S., Hildesheim,Dosemeci. (1993). Non risk factor factor for nasopharyngeal carcinoma in the philippines:result from a case control study. *International Journal of Cancer*, 722-729.