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# DEVELOPMENT OF ZERO EMISSION FORMALDEHYDE PLYWOOD AS AN ECO-FRIENDLY PLYWOOD FOR SAFER AIR

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**Abstract:** Nowadays, plywood market is world-wide consumption and trend is toward not only local consumption This is due to huge demand for quality plywood required in construction industry. Generally, phenol formaldehyde resin commonly referred as a thermal based adhesive in plywood industry, it provides the strong structural bond and moisture resistance durability for various exterior and marine grades of plywood. When formaldehyde concentration in air exceeds 0.1 ppm level, individuals may encounter adverse health effects such as burning sensations in the eyes, nose, and throat coughing, wheezing, nausea and skin irritation. In 1980, laboratory studies elevated that exposure to formaldehyde could cause nasal cancer in rats. The International Agency for Research on Cancer (IARC) announced formaldehyde chemical as a human carcinogen. Therefore, this research work is aimed to develop a new green plywood, by the replacing the phenol-formaldehyde resins with a mixed epoxy, silicone polymer resin as a zero emission of formaldehyde in construction industry. Their chemical bonding properties are compared with urea formaldehyde-based adhesive and phenol- formaldehyde resin. Modified adhesive formulation contributes better performance of veneer based plywood or particle board production without changing any properties during production process with improvement in overall properties. This new formulation of adhesive based on epoxy resin with silicone resin mix and applied for making green plywood construction building products. Further investigation also includes the moisture absorption characteristics, compression test, emission test, heat resistant capacity, and anti-termites, borer proof plywood.

**Keyword:** green plywood, silicone resin, epoxy resin, adhesives, zero formaldehyde emission.

**1.0. Introduction**

Plywood belongs to a class of essential building materials which is made of wood called "sheet goods." They are commercially classified as Hardboard, particleboard, melamine, OSB (oriented strand board), and MDF (medium density fiberboard). There are several varieties of plywood available on the market, some intended just for internal usage and others for external uses (J. Wang, N. Jiang, H. Jiang, 2009). These include marine plywood, which is used for projects that will be exposed to high humidity or wet conditions (Kandelbauer et al. 2007, Dunky et al. 1998, 2004), which is also applied for making decks, boats, outdoor furniture, and further structural plywood also known as softwood plywood, which is used for sheathing, flooring, roofing, and underlay applications. The primary materials for furniture production and interior house construction (e.g., flooring, wall panelling) are based upon the wood composites-based panels, whose representative products include oriented strand boards (OSB) (Steinhof et al. 2014, Despres et al. 2007, Chung et al. 1994). Furthermore, several nations such as the United States, Canada, and Scandinavian countries utilise these items for external purposes through the application of certain special varnish coatings (N. Ayrilmis, 2012) for example, prefabricated homes and roofing. Formaldehyde-based thermosetting resins are used to bind wood particles, fibres, or veneer sheets together to create wood-based panels (J. Bishopp, 2012). The latter combine the benefits of cheap cost, maximum performance in board manufacture, and high adhesive bonding reactivity (J. M. M. Ferra, M. Ohlmeyer, A. M. Mendes, 2011). Globally, formaldehyde resins (liquid form) are used 15 million tonnes in annually (Kandelbauer et al. 2007, Dunky et al. 1998, 2004). The comparable amount in Europe is close to 6 million tonnes, of which UF resins account for 80% (P. Girods, A. Dufour, Y. Rogaume, 2008). In addition, for making UF resins, this resin is used effectively in interior grade panels manufacture due to their hydrolysis susceptibility, free nonreacted formaldehyde (R. C. Dante, D. A. Santamaria, and J. M. Gil, 2009) that plays a role in the issue of formaldehyde emission from panel products not only during manufacturing and also in services causing a major issue. In the latter, indoor air pollution results from the prolonged formaldehyde release caused by the resin's continuous hydrolysis (Li et al. 2015, 2014). Formaldehyde is a naturally occurring component of wood, some of the emissions also come from the wood itself. Mostly phenol formaldehyde adhesives are essential components that are commonly used in the production of plywood, medium-density fiberboard, oriented strand board, and laminated veneer lumber and wood-based composite panels (M. Y. Naz, S. A. Sulaiman, B. Ariwahjoedi, 2014). This is a globally used thermosetting adhesives in brand name of urea-formaldehyde (UF), phenol-form-aldehyde (PF) (W. Stark, 2010), and melamine-form-aldehyde (MF) adhesives. Synthetic UF resin adhesive is an inexpensive, colourless adhesive that is used for binding the veneer sheet. According to L. Ricciotti, G. Roviello, O. Tarallo, et al. (2013), UF resin has low water resistance and a greater emission of formaldehyde, which is again detrimental to human health and to the environment. Due to its superior thermal ability and water resistance, the MF resin glue is costlier (S. Jahromi, 1999). For external applications, this glue is perfect. While MF resin glue needs a considerably higher curing temperature than the UF resin adhesive, it emits less formaldehyde. In 2014, A. Pizzi and C. C. Ibeh reported for large-scale applications, the PF resin glue is commonly utilized since it forms robust interconnections, that are resistant to ageing and solvents. When making wood panels, this glue needs long curing and drying period at higher temperature. Each of these three traditional adhesives has flaws that might be improved by changing the formulation (S. Ullah and F. Ahmad, 2014). Therefore, several research has focused on formaldehyde-free adhesives, such as soybean-based adhesive and isocyanate adhesives, in an effort to reduce the hazardous gas emissions of these formaldehyde-based adhesives (C. Devallencourt, J. M. Saiter, A. Fafet, and E. Ubrich, 1995). Products based on petrochemicals have been replaced with sustainable and renewable materials are introduced: soybeans (M. Zanetti and A. Pizzi, 2003). The traditional glue made from soybeans is affordable and non-toxic. Unfortunately, due to the presence of various amino acid compositions and multilayer structures of the amino acids, this adhesive has poor water resistance (Kim, M., 1999). Soybeans have been modified by using a variety of techniques, such as acid, alkali, organic solvents, detergents, urea, enzymatic agents, exposure to heat, Guo, X., Xie, X., Du, G. (2016), and more. These procedures raise the cost production and complicate the manufacturing process. The Chinese National Standard (GB/T17657-2013) states that the wood bonding strength complies with type II plywood (Sun, E., Huang, H., Wu, G., 2014), and the glue based on soybeans has a solid content of mostly less than 37%. For wood products used in construction, the European standard EN 13986 (Qu, P., Huang, H., Wu, G., Sun, E., Chang, Z., 2015) has been in good effect since 2004. Depending upon amount of formaldehyde emission generated, these boards are categorised into emission classes (E1–E3) (Arancibia, M.,López-Caballero,2014). A board must not leak more than 0.1 ppm of formaldehyde under precisely controlled test settings in classified as an E1 class (Chung, I., Maciel, G., 1994).

Formaldehyde is classified as a "carcinogen to Humans" by the US Environmental Protection Agency (EPA) in a 2010 report. Therefore, several years later, the EPA released a document defining the maximum emissions of formaldehyde from various types of wood-based panels, which are typically in the range of 0.05–0.13 ppm (Park, B.-D., Chang Kang, E. and Yong Park, J. 2006). Formaldehyde's has negative perception, therefore rules are framed for reducing emission levels and have been implemented (Matyasovsky, J., Sedliacik, J., Valachova, 2017). In continuous for manufacturing green plywood, we have have designed and synthesized a novel adhesive formulation in this study (Li et al. 2015, 2014), which is applied in the construction sector to create plywood processing, interior decorating features, mainly used for the building materials and furniture's of free from formaldehyde emission product. This plywood is structurally stable product, in different thicknesses and sizes. It also possesses superior dimensional stability, a high strength to weight ratio, as compared to solid wood (Dunky 2003, Frihart 2012, Mantanis et al. 2018). It may frequently use as an affordable substitute for solid timber. Therefore, this research work mainly focused to develop the green plywood as a prototype one, possessing mechanical, durability and no formaldehyde emission (Smythe, L. E.,1952) are studied for sustainable development.

## 2.0 Materials and Methods

The following analytical grade chemical materials were utilised without additional purification: phenol (99%), formaldehyde aqueous solution (37%), solid urea (99%), silicone resin, epoxy (96%), kaolin clay and resorcinol (99%). Plywood panels were made from rotary-cut alder wood veneer (Alnus glutinosa Goertn.), which had dimensions of 300 mm × 300 mm × 1.6 mm and an average moisture content of below 6%. In order to reduce the impact of wood structural flaws on the experiment's outcomes, veneer sheets from several tree species were chosen and assessed for making the plywood panel manufacturing. After the veneer sheets were examined closely, free from fractures, curling, and colours of relatively consistent thickness were chosen. There were no obvious flaws in the wood's look that could be seen.

Methodology:

- The Synthesis of Resins
- The manufacturing of resin involves a multistep process

The primary ingredient in this adhesives is epoxy resin. It is typically derived from the reaction of epichlorohydrin and bisphenol-A or other similar compounds. The selection of the epoxy resin can impact the adhesive's properties, such as strength, flexibility, and temperature resistance. The epoxy resin, hardener, and additives are accurately measured and mixed together in a controlled environment. This mixing process may be automated to ensure precise ratios. The mixed epoxy formulation is often subjected to a vacuum degassing process to remove any entrapped air bubbles. This step is essential to ensure a strong and void-free bond. The uniform mixing of these components is crucial for achieving the desired adhesive properties. Along with equal proportion of liquid polymerized siloxane, with organic side chains is called silicone oil is added and mixed thoroughly to get a homogeneous dispersion. This additive is most significantly known as polydimethylsiloxane. Due to their lubricating qualities and comparable heat stability, these polymers are of economic importance. The polymer backbone is made up of silicon and oxygen atoms that alternate (...Si−O−Si−O−Si...). The tetravalent silicon centres can have many different groups bonded to them, although methyl or occasionally phenyl is the most common substituent. Trimethylsilyl groups end-cap several linear polymers used to make silicone liquids. 5% of kaolin clay filler is also added into adhesive mix while preparation.

### Application of this adhesive towards plywood manufacturing

At first the selected plywood veneers are taken which is free from any surface defects, fungus attack. It is then cleaned to remove any surface dust and dried for removing moisture, grease, or any contaminants. Then apply uniform layer of the prepared mixed adhesive colloids on the surface of the plywood veneer using a brush or by roller. Repeat for even coating, avoiding any excess adhesive that might cause uneven bonding which is homogenous and free from lumps. Align the plywood veneers carefully for multilayered sheet of different thickness. Place the adhesive-coated veneer onto the next layer with proper alignment and contact. Apply a pressure for sufficient load to promote good contact and bonding adhesion, but not so high that it squeezes out all the adhesive. Allow the adhesive to cure for 3 hrs time and conditions (60 degree celcius temperature and humidity). Avoid disturbing the assembly during the curing process to ensure a strong bond. Finally Trim any excess adhesive that may have squeezed out at the edges during the pressing.

## 3.0 Results and Discussion

Green plywood is produced which shows low shrinkage, low cracking, high heat resistance, low moisture absorption, strong binding layer, good termite and biofouling resistance, resistance against microorganism growth, and low cost scalability.

Plywood is made up of many layers of veneer sheets or a combination of particles to form particle boards with varying thicknesses, such as 3 mm, 6 mm, 9 mm, and 12 mm, depending on the required length and thickness, good hardness, smooth surfaces, and very few structural flaws. The most significant is that it exhibits material qualities like hardness, reduced bending strength, less cracking during fabrication, and increased durability in harsh environmental conditions. The observed findings show that the plywood does not exhibit the most prevalent problems with conventional plywood peeling or welling even at low temperatures. These adhesives also preserve the natural color of wood, such as brown, yellow, or orange, for an extended period of time without interfering with the cellulose or tannin of natural cellulose wood. The wood's grain structure is preserved as well and observed with laminated thin film. To demonstrate that the

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| Compression test | 332.780 KN$^2$<br>DISPLACEMENT<br>7.7 KN$^2$<br>BREAKING LOAD<br>149.580 KN$^2$<br>YIELD LOAD 338 KN$^2$ |
| Tensile test | MAXIMUM 3.7 KN$^2$<br>BREAKING LOAD 2 KN$^2$ |
| Water Absorption test | BOIL WATER TEST<br>BEFORE – 0.43 KG,<br>AFTER- 0.46KG<br><br>NORMAL WATER TEST<br>BEFORE-0.34 KG,<br>AFTER-0.38 KG |
| Ph<br>Con<br>TDS | 7.67<br>31.3 S/cm<br>410 mg/l |

moisture and water absorption property of the plywood, a variety of tests have been conducted on the plywood. The results indicated low water absorption property even in the case of hot and cold water immersion without any swelling or delamination. This is due to the hydrophic nature of siloxane substance. The engineered plywood may also be combined with plastic materials, such as low-density and high-density sheets, to reduce weight and increase durability even when exposed to heat or moisture. The prepared plywoods indicated good compressive strength of 332.780 KN$^2$ indicating the well bonded strength and tensile strength. This also due to additive filler clay improve the mechanical strength of bonding and heat resistance. The moisture absorption test is observed by taking a standard size of the same kept between the room temperature and also at 100 degree celcius. The amount of weight loss of plywood sample dried at 100 degree celcius. It indicates 6 to 7% moisture. It also indicates the adhesive are resistant to moisture. The prepared plywood shows high bearing strength indicating good nail-holding capacity, ie the plywood is not easily spilited of, it may be perfect bonding between each layer and less moisture absorption. The long term leachate obtained by plywood immersion indicates the neutral Ph value 7.34, and TDS value of 410 mg/l. This value confirms the absence of formaldehyde chemical substances.

**3.1. Tables and figures**


Table 3.1. Test Results

PH Test Water Absorption Test

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Fungal Test

- Determination of Density And Moisture Content
- Determination of Ph Value
- Determination of Conductivity
- Acidity and Alkality Resistance Test
- Compression Test
- Tension Test
- Water Absorption Test
- Formaldheyde Test
- Fungal Test
- Nail Bearing Test

## 4.0 **Conclusion**

The preapred plywood binders offer pertinent details regarding filler materials, processing, properties of plywood manufactured. The produced green plywood possesses no formaldehyde emission of better mechanical properties. The most significant characteristic is that it exhibits strong material qualities like hardness, reduced bending strength, less cracking during fabrication, and increased durability in harsh environmental conditions. Finally, the prepared adhesive formulation that uses silicone oil and epoxy acts as a good binder, these plywood is ecofriendly designed and sustainable one, plywoods have no formaldehyde emissions overall, making them nontoxic, environmentally friendly, and suitable for interior design and decoration in automotive industry. Plywood that has been manufactured will also serve as the base support material for connecting mica or plastic printed sheets with excellent surface qualities for long-term uses, giving the product a more aesthetically pleasing look. Furthermore, the results show that even at low temperatures, the plywood does not exhibit peeling or swelling, which are frequent issues with conventional plywood. These adhesives preserve the natural colour of wood, such as brown, yellow, or orange, for an extended period of time without interfering with the cellulose or tannin of natural cellulose wood. The wood's grain structure is preserved as well. To demonstrate that the water quality meets requirements, a variety of tests have been conducted on the plywood. The test results show that the produced plywood has high tensile and compressive strength, minimal water absorption, and no breaking when tested with nails. The engineered plywood may also be combined with plastic materials, such as low-density and high-density sheets, to reduce weight and increase durability even when exposed to heat or moisture. The cost of the prepared is considerably low cost when comparing to the price of commercially available green plywood's in markets. The optimization of this product is of our future research work.

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