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Radio Frequency Gluing Technique for Wood-to-Wood Bonding: Review

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Abstract

White glues, also referred to as polyvinyl acetate (PVAc) adhesives, are thermoplastics that soften when heated to a specific degree and re-harden when cooled. For general assembly tasks in the joinery business, such as edge gluing, wood veneer, and edge bonding, white glues have been used. White glue requires a prolonged setting time to achieve adequate handling strength as it solidifies through evaporation or absorption of water by the wood. Cold press and hot press techniques are used to bond wood substrates. Recently, white glue is frequently used as a wood adhesive with dielectric heating systems to prevent this and enhance production speeds. Radio frequency (RF) curing is merely a technique for heating glue lines in wood-to-wood joints. It considered a source of heat, like steam and electricity. In order to bond wood substrates with the least amount of clamping time, the RF produces a very rapid, uniform rise in temperature. In this review paper, we discussed the radio frequency curing technique, their mechanism and troubleshooting to achieve perfect wood bond in joinery segment.

Keywords

Radio Frequency, Curing, Wood, Adhesive, Polyvinyl Acetate

1. Introduction

Polyvinyl Acetate (PVAc) wood adhesive is an odourless and non-flammable adhesive, which is commonly used in furniture, joinery and other wood product manufacture at room or low temperatures [1] [2]. PVAc emulsions are frequently used to bind a variety of porous materials at room temperature, including wood processing, packaging for furniture, decorating buildings, texture bonding, and print bonding [3]. PVAc emulsions are prepared by free radical polymerizing vinyl acetate (VAc) monomers in presence of polyvinyl alcohol (PVA) as a col-

loid as shown in Figure 1 [4] [5] [6].

However, there are some disadvantages to PVAc emulsion-based adhesives as well, such as their poor mechanical stability, poor thermal performance, and poor moisture resistance. These shortcomings have a direct impact on the segment's integrated value of final uses and processing in the wood joinery industry. Numerous studies have been conducted thus far to enhance the performance characteristics of PVAc, including co-polymerization and co-blending [7]-[14]. In some experiments, active monomers called N-hydroxymethyl acrylamide (NMA), acrylic acid, methacrylic acid and vinyl ester of neodecanoic acid (VeoVa 10) were added to PVAc-based emulsion adhesives in order to enhance the chemical, physical, mechanical, and thermal properties of PVAc. Under the right acidic circumstances, the molecules could be further cross-linked and cured [15] [16]. Wood to wood bonded is doing by cold press, hot press and RF curing method.

Cold and hot press

Cold presses are working on pressure. The cold press is meant to get maximum pressure for a short period of time. In this press, 10 to 20 pieces of wood panels pressed at a time, for approximately 20 - 30 min, then bond set for 6 to 8 hrs and the bonded assembly is ready to use [17]. Cold press gluing machine is shown in Figure 2.

Hot presses are working on heat and pressure. The heat makes the faster evaporation of water from glue, so the press time is shorter. One wood panel at a time, press 3 to 5 minutes, then bond set for 4 to 6 hours; then it is ready for further processing [18]. Hot press gluing machine is shown in Figure 3.

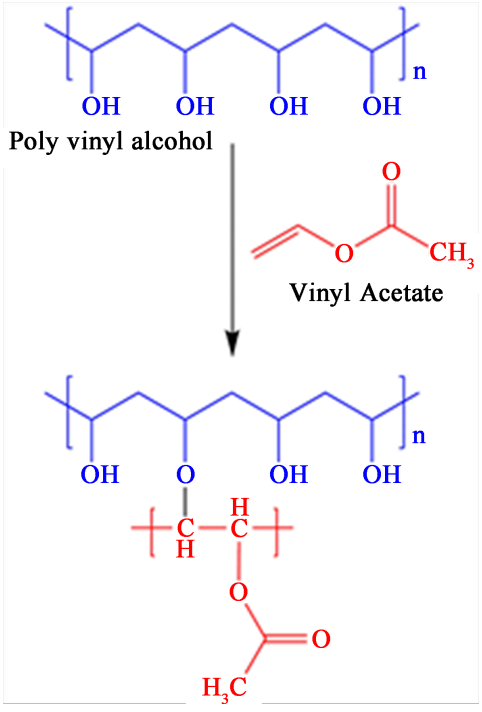

Figure 1. PVA stabilized PVAc emulsion [6].

Figure 2. Cold press gluing machine.

Figure 3. Hot press gluing machine.

2. Radio Frequency Curing

The field of application of radio frequency (RF) intended for wood adhesives is based on the dielectric heating induced by electromagnetic waves, which can heat materials that are poor conductors of heat [19] [20] [21]. The first patents relating to application of RF in bonding can be found already at the beginnings of the 1940's [22] [23]. However, they did not mention the adhesive performance relating to operating conditions. Although a large body of work relates to the health effects of RF radiation [24] [25] the literature on the impact of applying RF to PVAc bond lines on bond performance of wood-to-wood assemblies is

limited to the study of the substrate grain orientation like radial-radial, radial-tangential, and tangential-tangential and of the wood moisture content [26] or to energetic issues [27].

The use of radio frequency is merely a means of obtaining heat to cure glue lines in wood-to-wood joints. The means of generating heat with radio frequency does differ from other sources. The electrical impulses or energy that is generated in suitable equipment are transmitted at very high cycles or frequency. Their passage through any mass results in some development of frictional heat, the degree dependent upon the electrical properties of this mass. In the case of wood which is a reasonably good insulator, considerable heat is realized. RF current, however, causes a uniform heating of the mass, in this case wood, so that the center is heated as fast and to the same degree as the outer surfaces. This contrasts with other heat sources like steam where the heat migrates slowly from the surfaces to the center. The radio waves in RF heating range in frequency from 2 to 30 megacycles which is slightly above the so-called "broadcast range" of 0.5 to 1.6 megacycles. In radio broadcasting, the waves are transmitted from a generator to an antenna where they are broadcast indiscriminately. However, in the case of gluing equipment the waves are transmitted or confined between plates or electrodes, and thus are used as a heat source when some mass like wood is inserted between these parts.

RF heating is advantageous over alternative methods, such as hot-pressing, in accelerating the adhesive drying because of the higher efficiency of the method, which is able to selectively heat the glueline when still wet. On the other hand, only a relatively limited temperature increase in a dry substrate is induced and restricts the degradation of adhesive.

Advantages of RF curing over Heat pressing:

- The RF heats only the glue line, making the radio frequency machine efficient, fast and energy saving.
- High energy transfer efficiency.
- Uniform heating within the product.
- Short process time.
- Reduced equipment dimension.
- Instant and accurate process control [28].

3. Principles at the Basis of Radiofrequency Heating

The field of application of RF intended for wood adhesives is based on the dielectric heating induced by electromagnetic waves. In fact, the interaction of materials with electromagnetic radiation can be differentiated according to three different processes: absorption, transmission, and reflection. Materials able to absorb radiation are called dielectrics, and those showing intense absorption can develop high quantities of heat under irradiation. On the opposite, in materials whose surface can reflect radiation, only a limited part of energy is absorbed and therefore they do not highlight any temperature increase. Electrically conductive

materials, such as metals, belong to this latter type, whereas PVAc dispersions evidence absorption by irradiation. The dielectric characteristics of materials are usually related to the presence of polar groups in their molecular structure. These groups constitute electrical dipoles. Of course, the example of water molecules is the easiest to understand: water molecules are natural electrical dipoles owing to the different electronegativity between oxygen and hydrogen atoms. However, dipoles may be either a natural feature of dielectric materials or be induced by intense electric field, which is able to distort the interatomic distances in molecules, thus producing temporary dipoles in selected materials. In general, polar substances strongly interact with radiofrequency, whereas completely polar compounds sharpen weak interactions with electromagnetic radiation. If such dipoles have sufficient freedom to move, they tend to align with an existing electric field, through molecular rotation. In fact, the applied electric field aligns the randomly oriented dipoles in a direction opposite to that of the same electric field as shown in Figure 4.

Of course, if the electric field varies its intensity and direction with time, the dipole orientation will also tend to vary accordingly. However, if the variation frequency is sufficiently low, dipoles follow these variations keeping well-aligned to the electric field: in this case, the irradiated material will be transparent to radiation. On the other hand, a very quick inversion of the electric field causes the chaotic, not-aligned with the electric field, rotation of electrical dipoles. Therefore, an internal friction is produced among polar molecules, which is able to produce direct and uniform heating of the interested material. In that way, energy associated to the electric field is transformed in kinetic energy and therefore in heat. If tan δ is too low, heating takes place slowly and heat losses could even prevent the attainment of the desired temperature. If the loss factor is too high, the material would arc to the work electrode.

PVAc dispersions used as wood adhesives are widely processed with dielectric heating systems. In fact, the adhesive loss factor, tan δ, for PVAc dispersions is higher than that for sufficiently dry wood and wood-based materials and, as a consequence, the interaction of electromagnetic radiation with a PVAc-glued assembly, induces an easier heat dissipation into the PVAc glue compared to the substrate.

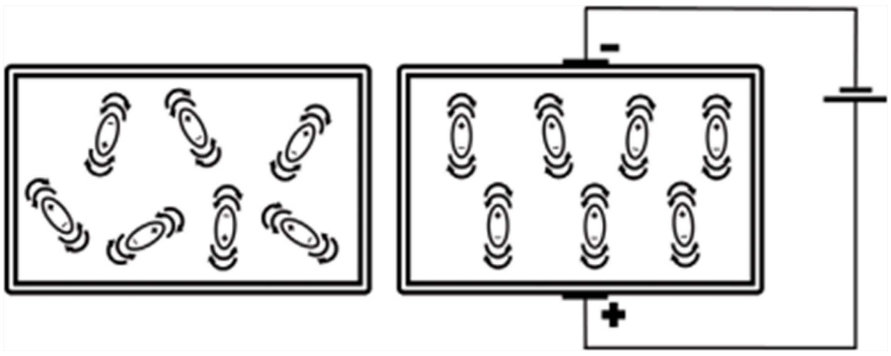

Figure 4. Molecular rotations movements in presence of electric field.

4. Types of RF Heating

There are three types of RF heating recognized in the wood gluing field and their terminology stems directly from the location of the glue lines in relation to the direction of current flow.

4.1. Perpendicular Heating

This type is utilized to heat the entire mass of material placed between electrodes. Here, the glue lines are parallel to the electrodes but perpendicular to the flow of current between electrodes; hence, the term "perpendicular" is derived and assembly is shown in Figure 5.

This arrangement is generally used to bond flat or curved plywood, or for laminating purposes.

4.2. Parallel Heating

This set-up has the glue lines running at right angles to the electrodes, or parallel to the flow of RF current between electrodes. Thus, the name "parallel" has been derived and assembly is shown in Figure 6.

Since the glue lines are normally more conductive than the wood, current is usually concentrated into the area of the glue line to give a pattern of selective heating. As a result, very fast cures can be obtained in relatively short periods of time. This method of bonding is used primarily for edge-gluing applications.

4.3. Stray Field Heating

This type of heating has both electrodes located on the same side of the glue line. Although much energy flow passes directly between the electrodes, they can be

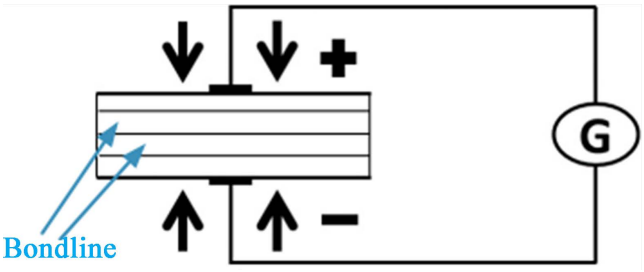

Figure 5. Perpendicular heating.

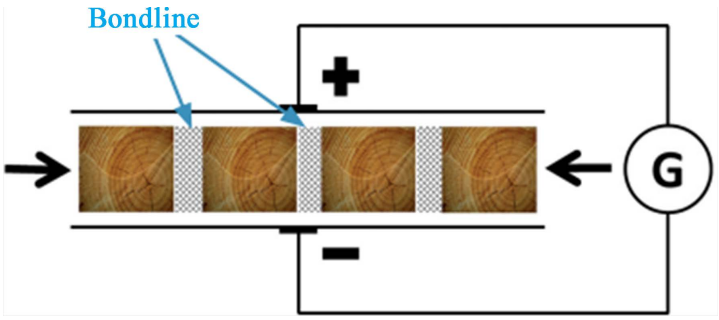

Figure 6. Parallel heating.

designed to permit the energy to radiate outward from the electrodes and it is this phenomenon that adjacent mass of wood and glue lines to cause cure of the adhesive. Thus, the term "stray field" has been derived and assembly is shown in Figure 7.

This type of heating is generally utilized where it is impossible to place assemblies between electrodes for either perpendicular or parallel heating.

Depending on the specific manufacture process, three different radiofrequency systems are used in wood industry: perpendicular heating, parallel heating, punctual heating. In the perpendicular case, both the substrate and the adhesive layer are positioned perpendicular to the electric field. For instance, this type of process is used in veneering and plywood manufacture. In parallel heating, the electromagnetic field is parallel to the glue lines. This process is mostly used in solid wood panels manufacture. In punctual heating, the radiofrequency is only applied in selected areas, and not on the whole bond line. This allows the gluing of large surfaces or of parts where the geometry is not regular, and it is mostly used in panels edge gluing [29].

5. Application Requirements for RF

5.1. Spreads

For all types of heating, the adhesive spread should be only sufficient to show a slight bed of squeeze-out when the pressure is applied to the assembly.

5.2. Assembly Time

Due to the rapid rate of cure, adhesive transfer must be accomplished within the first few seconds after pressure is applied; therefore, the total assembly time is limited to less than the time it takes the spread adhesive to dry to the touch.

5.3. Estimating Curing Cycles

Although the time required to obtain cure of the resin by radio frequency heating depends on numerous factors such as species of wood, its mass, area of glue lines and temperature rise required, there are nevertheless ways of quickly estimating the cure cycle involved. In the case of perpendicular gluing, first determine the weight of the wood and adhesive involved in a given charge and multiply this value by the specific heat of wood (0.45).

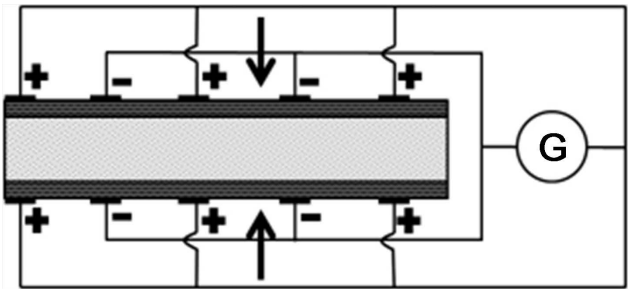

Figure 7. Stray field heating.

6. RF Curing of PVAc Adhesive

Heating by radiofrequency is a very effective heating system when water-based emulsions are used. In the practice, this means that, when temperature is measured as a function of time, it increases much more quickly in joints heated under radiofrequency than in those heated with traditional hot-pressing. This also implies that radiofrequency dramatically decreases the time needed for drying assemblies. As a consequence of temperature increase, RF exposure causes in joints a rapid decrease of moisture content in glue at the substrate/glue interphase. The film formation process consists in transforming a stable dispersion of colloidal polymer particles into a continuous solid film. Because of moisture content decrease and the resulting film formation advancing, RF exposure causes in joints a rapid increase of shear strength. It was also shown that excessive heating induces discoloration of bondlines and it can mechanically weaken the polymer constituting the adhesive.

PVAc dispersions are widely used as wood adhesives with dielectric heating systems. However, little is known about the effects of RF exposure or heat on the adhesive characteristics and on the performances of bonded joints. In this study, the properties of bonded joints exposed to RF were compared with hot pressing. Results evidenced that the effect of both RF and heating was to appreciably speed up the drying process. However, when high values of energetic impulse were given to the assemblies, permanent changes were induced into the polymeric glueline. This occurrence was a time-driven process and reflected mainly on the mechanical performance in wet conditions. The reason of such behavior was connected to the PVA phase present inside the polymer, and a role was also assigned to $AlCl_3$, used as complexing agent of the polymeric protective colloid [30]. It is commonly believed that the addition of $AlCl_3$ has a dual effect: 1) it increases acidity, and thus promoting the crosslinking reaction with the specific comonomer usually added to the dispersion and 2) it interacts with the electron-donating groups of the polymer, such as the PVA chains and the PVAc chains containing grafted PVA, with the formation of structures like chelates [31] [32]. Isocyanate hardener in PVAc adhesive was used to enhance the performance of RF press wooden assembly. The impact of exposing edge-glued panels to different RF press times was investigated via both compression shear block tests and dynamic mech. analyses. Edge-glued panels were made of yellow-poplar bonded with PVAc adhesive [33] [34].

7. Troubleshooting

Tables 1-3 are a listing of the most common problems, causes and recommendations in RF gluing technique [35].

8. Conclusion

Radiofrequency heating is an efficient heating technique but it is expensive to manage and operational costs are appreciably reduced compared to hot-pressing.

Table 1. Troubleshooting for under cured wooden joint.

Under cured wooden joint	
Possible causes	**Recommendation**
Low power supply	Increase power supply
Short curing time	Increase curing time
No or low clamping pressure	Check filler boards and pressure system
High moisture content in wood substrate	Maintained 6% - 8% moisture content in wood substrate
Improper isocyanate hardener mix	Mix hardener properly

Table 2. Troubleshooting for cured joint resulted into weak bonds.

Cured joint resulted into weak bonds	
Possible causes	**Recommendation**
Slightly under-cured	Check power supply and time settings
Incorrect or improper pressure	Check edge pressure
Irregular or burnished surfaces	Check surface preparation
High moisture content in wood substrate	Maintained 6% - 8% moisture content in wood substrate

Table 3. Troubleshooting for Bonded wooded panel split at the ends.

Bonded wooded panel split at the ends	
Possible causes	**Recommendation**
Poor substrate preparation	Check quality of gluing surface/end fit
Pressure shoes overlapping on next panel	Check and correct machine pressure setting if necessary
Shrinkage of wooden assembly	Maintained 6% - 8% moisture content, 30% minimum relative humidity and glue within 24 hours of preparation

Table 4. Troubleshooting for burning in joints.

Burning in joints	
Possible causes	**Recommendation**
Power supply too high	Reduce power supply
Improper hardener level	Check and correct if necessary
Long assembly time	Press within five minutes
High edge pressure	Reduce edge pressure

The glue amount spread on the adherends does not play an appreciable role in determining the mechanical performances of assemblies heated under radio

frequency. This is related to the limited amount of water in bondline compared to moisture content in wood-based adherends. RF exposure causes a rapid decrease of moisture content in glue at its interphase with substrates. RF exposure causes a rapid increase of shear strength in joints. The shear strength increase rate depends both on the chemistry of the polymer constituting the dispersion and on the geometry of the assembly. Radiofrequency dramatically decreases the time needed for drying assemblies prepared with PVAc. The presence of dipoles is responsible for the dielectric characteristics of materials. Heating is due to molecular friction among the dipoles. Here, we discussed, influence of temperature, induced by RF exposure as well as direct heating, in considerably improving the coordination capability of $AlCl_3$ toward PVA molecules, which in turn appreciably improve the mechanical and water-resistance properties of glued films. In coming future, RF curing will be the most significant technique for making wood joints in joinery industries.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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