Process considerations to achieve optimum weld strengths of Wood Plastics Composites using advanced Vibration Welding technology

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As the uses for Wood Plastic Composites increase manufacturers are looking for new and cost effective ways to bond these materials. This paper reviews the vibration welding process. Understanding of the vibration welding process and limitations when applied to Wood Plastic Composites. Examples of vibration weld joint geometry and examples of potential weld strengths that could be achieved.

Materials/Plaques

Weyerhauser Chiocedek Premium deck boards manufactured by Advanced Environmental Recycling Technologies (A.E.R.T.) was used in the experimentation for this paper. The extruded material consists of a 50/50 blend of oak chips and recycled Polyethylene made from thin film. (Fig. 1) Polypropylene injection molded fasteners attached to several off the shelf chipboard samples are also presented. The exact chemical properties of the chipboard where unknown. (Fig. 2, 3)

Welding Equipment

A linear vibration welder (Dukane VWB3500) was used for this research. (Fig. 4) One fixture was attached to the upper vibrating platen and a second was fixed to the lower platen. The upper and lower tooling are aluminum and have cavities machined to hold the material solid during the welding process.

The injection molded plastic attachments where welded on a linear vibration welder (Dukane VWA3700) The upper tool is a flat plate with a clearance hole for the post to hold the part. The chipboard was held on the lower table by skid tape. Skid tape is simply adhesive backed sandpaper used in the application to keep the parts from sliding during the vibration phase of the weld.

The Vibration Welding Process

Linear vibration welding physically moves one of two parts horizontally at 120 to 240 Hz, under pressure, creating heat through surface friction that melts and welds the parts together. Typical horizontal movement (Amplitude) is between .050 - .070” The vibration welding machines can deliver up to 5000 lbs of clamping force.

Welding stages include: 1) Solid Friction; 2) Transition; 3) Optimum Joint Strength; 4) Cooling.

1. Solid Friction

Linear motion of one part against another generates friction between the two surfaces, producing heat at the joint.

2. Transition

The parts begin to melt at the joint. High heat generation from the high shear rate causes further melting and a thicker melt layer. As the melted layer thickens, the viscosity increases and the shear rate decreases resulting in less heating. Pressure on melting parts promotes fluid flow to create the joint.

3. Optimum Joint Strength

The weld process is discontinued when the joint has reached its optimum strength. This is indicated when the parts melt at a rate equal to the outward flow rate at the joint.

4. Cooling

With pressure maintained on the joint, the material re-solidifies, forming a molecular bond.

Vibration welding can join all known thermoplastics including materials with up to 50 percent filler content. Vibration welders can also join many dissimilar materials with compatible melting points, composite materials and fabrics. The following materials may be assembled by vibration welders: amorphous resins such as ABS/PC, PVC, PMMA or PES; semi-crystallines such as HDPE, PA, PP and TEO. Vibration welders can also join fiber reinforced carriers such as wood fiber, textile fiber or Polyurethane Long Fiber directly or by claw effect, or with composite surface coating.

Process limitations when applied to Wood Plastic Composites.

Vibration welding process requires frictional motion; therefore it is critical the materials being joined have clearance to allow for the motion up to 1.8 mm The joint area in the motion direction cannot exceed 10 degrees variation from a flat plane. The process requires the two components being bonded to be held solid during the vibration process. In rigid injection molded plastic applications the part variations are minimal, therefore machined solid metal holding fixtures are used to hold part position during the welding process. Wood plastic composites are typically extruded materials that often have significant dimensional tolerances.   This makes it difficult to hold the materials from sliding during the welding process. One option is to hold the materials with a machined knurl pattern that penetrates into the material surface to hold the parts from sliding. This method however creates surface blemishes sometimes cosmetically unacceptable.

Large contact areas created in an attempt to bond two pieces of extruded material require significant machine power; therefore the actual bond area is limited. A joint profile reduces the contact area and allows for large pieces of materials to be bonded. This profile is commonly called an energy director. Energy directors are small raised details incorporated on one of the two pieces being bonded. (Fig. 6) Raised areas in an extruded material obviously can only be extruded in the direction of the extrusion therefore placement of the energy director is limited. Energy directors can be machined into the material however this adds an additional operation and handling costs.   When joining an injection molded piece to the WPC the energy directors can be molded into the attachment piece.

Bond strength can be attributed to two factors. Molecular bond, which is the actual, intertwines of the chemical molecules and mechanical bond, which is intertwining of the wood fiber into the resin. (Fig. 7-12)

Material composition has a major influence on bond strength. The strongest molecular bonds are produced when both parts are manufactured out of the exact same resin and of 100% virgin thermoplastic. Similar thermoplastics may be compatible only if their melt temperatures are within 100 F and they are of like molecular structure. Other factors that may influence bond strengths include hygroscopicity, mold release agents, lubricants, plasticizers, fillers, flame retardants, regrind, pigments, and resin grades

The vibration weld process does not produce any molecular bond of the wood fiber, therefore as the percentage of wood fiber increases, the molecular bond area decreases reducing bond strength. The size, shape and percentage of the wood fibers determine the mechanical bond effect.

The welding process produces a considerable amount of flash that may be cosmetically undesirable. (Fig. 1) One solution is to position the energy directors far enough away from the visible edge that the flash is contained. This holds true for attachment of injection molded parts to the WPC. In applications where the energy director is an extruded profile, a secondary operation may be required to remove the energy direct from the part edge area.

Joint Geometry

The joint or energy director was machined into the extruded material for this experiment. (Fig. 6 shows typical energy director for injection molded applications) The energy directors run the length of the part in two places. The profile was .5mm high x 2mm wide x 152mm long. (Figure 5) This produced 608 sq. mm of weld area for the first .5mm of collapse and 5792 sq. mm (9 sq. inches) for the second 1.3mm of collapse. As stated earlier, conventional vibration welders have limitation on the available power capability, therefore when determining the energy director size, the machine capacity needs to use in the calculation.

One recent project requires the attachment of 60 x 2.5” long sections. In order to achieve the strongest bond possible using this material it was calculated that the machine power capacity allowed for 34 sq. in. of weld area. The final design of the energy director was three raised energy directors 3/6 wide x 60” long.

Welding Parameters

6" deck material

Part #	Collapse distance Primary weld method	Weld pressure lbs	Weld time sec	Amplitude mm	Hold pressure lbs.	Hold time sec.	Notes
1	1	2536	1.36	1.8	2500	5	
2	1.8	2520	6.58	1.6	2500	5	
3	0.63	2579	7	1.6	2500	5	No energy director timed out, 7 sec.
4	1.85	2573	6.85	1.6	2500	5	
5	1.86	2574	6.02	1.6	2500	5	
6	1.84	2630	6.91	1.6	2500	5	
7	1.83	2542	6.51	1.6	2500	5	
8	1.86	2568	6.61	1.6	2500	5	
9	1.86	2579	6.79	1.6	2500	5	
10	1.83	2574	6.46	1.6	2500	5	
11	0.52	2598	7	1.6	2500	5	No energy director timed out, 7 sec.
12	0.5	2581	7	1.6	2500	5	No energy director timed out, 7 sec.
13	0.36	2591	7	1.6	2500	5	No energy director timed out, 7 sec.
14	0.59	2585	7	1.6	2500	5	No energy director timed out, 7 sec.

Injection molded fasteners to chipboard material

Part #	Collapse distance	Weld pressure lbs	Weld time Primary weld method	Amplitude mm	Hold pressure lbs.	Hold time sec.	Notes
All	.8-.9	200	2.5	1.8	200	5	

Test result

A pull fixture was built to measure weld strengths of the samples welded. Four samples pulled give clear evidence of the weld strengths that can be achieved. Part number 7 was cut in half so that two 3" parts could be pulled. 7a was pulled direct. 7b was pulled from one end in an attempt to simulate a shear force on the bond area. The shear forces required to separate the bond are approximately 30% lower the direct 90 degree pull forces. These are the samples pulled at the time of this paper writing. More samples are out to be pulled.

Part #	Sheer	Direct	lb.	Size
10		X	833	6"
7a		X	664	3"
7b	X		431	3"
8		X	901	3"

Conclusion

Based on current experience along with experimentation for this paper Vibration welding of wood plastic composites is a viable method of assembly. Cycle times for assemble are very short, with no curing time required. There are solutions for dealing with part variations tolerances due to the extruding process. Vibration welding is also a viable process for attaching injection molded components to wood plastic composites. Strong bonds can be achieved provided the injection-molded material has similar chemical properties as the base resin of the wood plastic composite material. This method of assembly requires no mechanical fasteners or expensive glues. As uses and applications for wood plastic composites increase manufacturers will continue to look for cost effective means to bond the materials to produce complete assemblies for the end users, vibration welding is a viable cost effective process that should be considered.

Bibliography

(1) Guide to Ultrasonic Plastics Assembly, Dukane Corporation IAS Division, St. Charles, Illinois, 1995

(2) Guide to Ultrasonic Assembly of Thermoplastics,1st Edition, American Welding Society, Miami, Florida, 2006

(3) Joint Design a Critical Factor in Strong Bonds, Engineering Design, Warren Kenny, Dupont

Figure 1. Weyerhauser Chiocedek Premium deck boards manufactured by Advanced Environmental Recycling Technologies (A.E.R.T.) Vibration welded
Shows example of flash when weld is close to the edge.

Figure2. Polypropylene injection molded fastener attached to off the shelf chipboard samples Injection molded

Figure3. Polypropylene injection molded fastener attached to off the shelf chipboard samples Injection molded

Figure 4. Linear vibration welder (Dukane VWB3500)

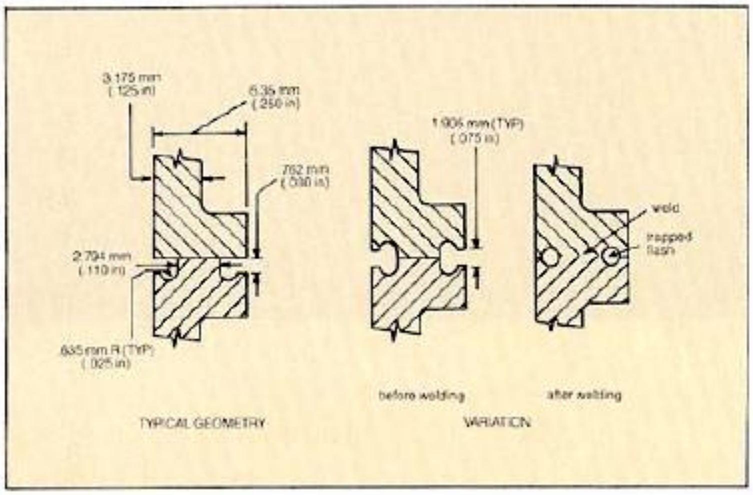

Figure 5. Typical vibration weld energy director design (Dupont)

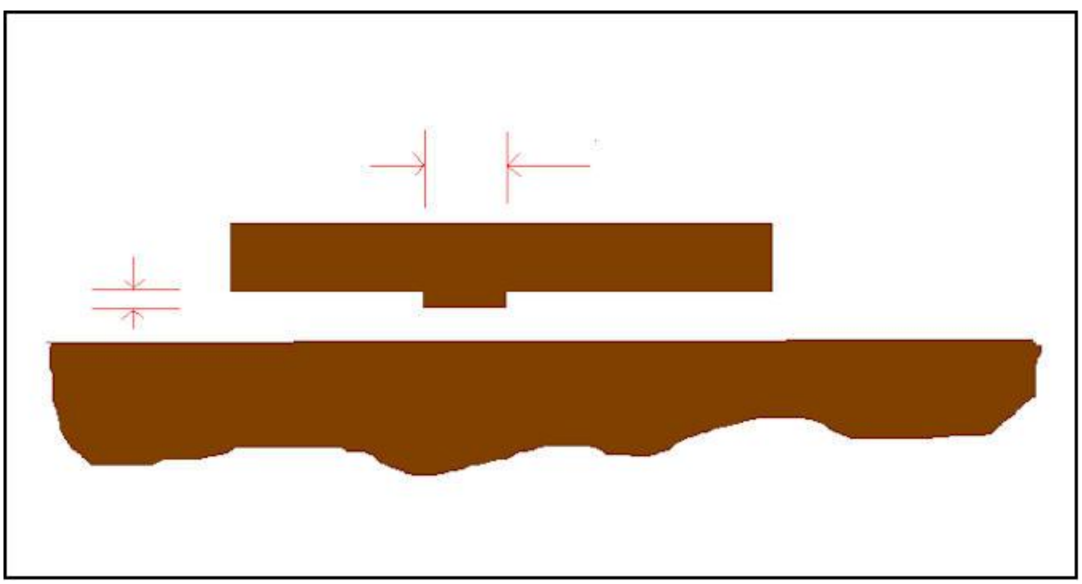

Figure 6. Detail design of samples

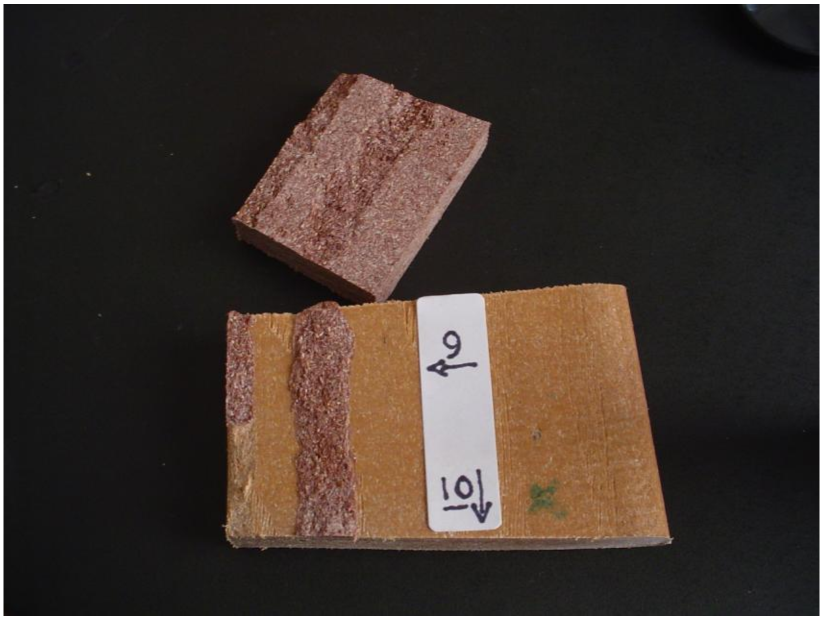

Figure 7. Show material bond at weld line after pull seperation

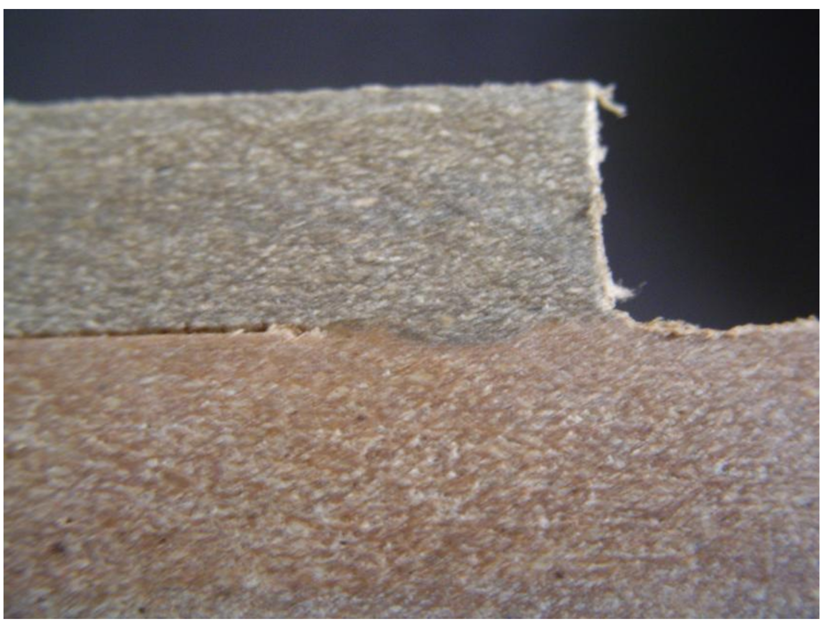

Figure 8. Magnified view of energy director area of bonded material

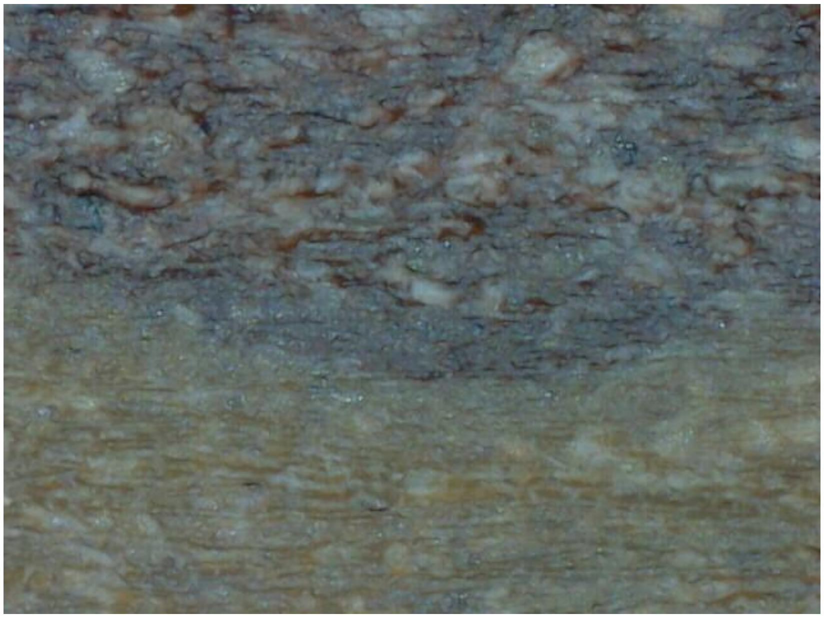

Figure 9.Magnified view of welded Wood Composite material. Shows molecular intertwine of polymer at energy director area.

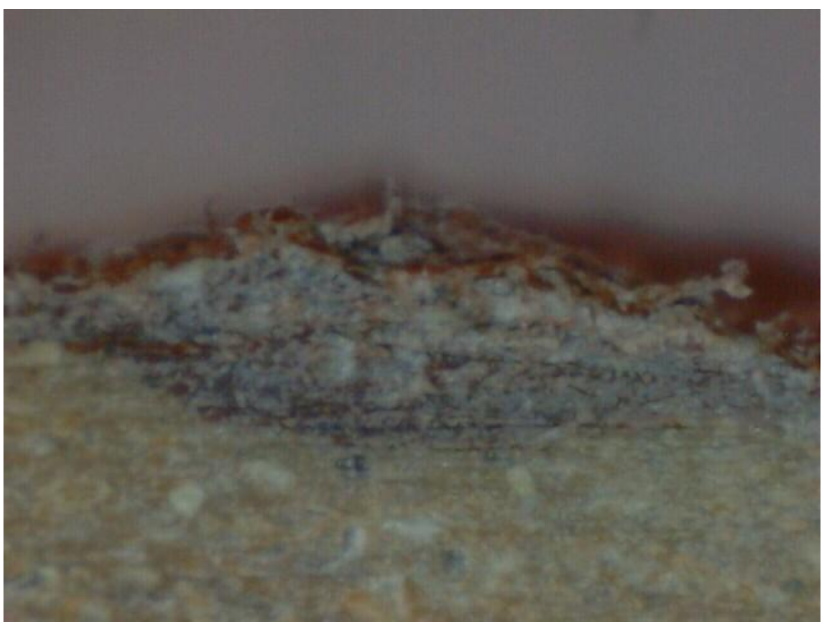

Figure 10. Magnified view of pull seperation of welded material.

Figure 11. Shows fracture area of sample pulled material

Figure 12. Shows magnified view of figure 11. Shows energy direct effect at bond line. Increased weld depth penetration