

# Joint connection with welded thermoplastic dowels & Wood Welding Technologies

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# ABSTRACT

Welding technologies are widely spread in the plastic and the automobile industries. These connection processes are fast and have high resistance, besides they can provide impervious joints. It was the automobile industry that made the first steps into the field of wood welding. Unfortunately most of the results of these investigations remained secret or archived without being followed up. Few information is therefore available but from these first experiments, it appeared that the technologies were adapted to wood.

SWOOD surveyed the wood industry to find out that there was an interest for this connecting technologies. Indeed, Wood Welding Technologies (WWT) offer new possibilities to joint porous material in a very efficient way. Wood is a porous material thus adapted to this technologies. Welding connections are economical (less wood moulding) and clean (dry connection, no liquid adhesive), impervious and densely jointed at the surface. But wood is not a homogenous material so that to tune the parameters for a constant qualitative work is not evident. The new generation of welding machines allow to meet these requirements.

One purpose of this paper is to present a state of art in the field of WWT with special attention to ultrasonic process. Second this paper presents the research already done or in progress by SWOOD. Finally, it summarises the range of applications of the various welding technologies for the wood industry.

# INTRODUCTION

In 1993, the Research and Development (R+D) department of SWOOD started to investigate WWT when a project of fundamental research in the field of ultrasonic wood welding was launched. The aim of this research was to get the basic data in this technology and to set the basis for future development projects with partners from the wood industry. Since 1997, encouraged by the good results obtained in tension and shear resistance of welded wood joints, opportunities to extend and apply WWT to timber construction showed up and were investigated.

In the mid of 1999, SWOOD launched a new project aiming to study the functionality and adequacy of alternative thermoplastic welding technologies such as vibration and spin processes. Indeed research had been exclusively focused on US technology but for some applications this method was not appropriate or too expensive. This study may give the basic information to launch further investigation for applications in the wood industry and construction. The data collected with this program may also help to convince future industry partner to invest in WWT.

Beside the research projects, SWOOD is involved in direct mandates with companies to help the implementation of a welding technology into their manufacturing process. WWT can be used in all activities of the wood industry such as joinery and construction. The range of WWT applications is wide as they virtually offer a solution to all glued or nailed joints.

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# HINTS REGARDING WWT

### Material

Within the frame of the projects carried out by SWOOD, several thermoplastic material were tested with varying degrees of success. On the whole, polyamides (PA), polycarbonates (PC) and acrylonitrile-butadien-styrene (ABS) showed the best welding results. In order to improve the resistance of the joint, actually the strength of the thermoplastics, the latter can be reinforced with glass or carbon fibres. A possible alternative to these three thermoplastics is offered by other materials like for instance polyolefins. This material may show good results as it has compatibilities with wood and accepts isocyanates as additive material.

Improvements regarding the resistances of the thermoplastic material are needed. To progress in this field, SWOOD cooperates with the chemical industry in order to find out the best additive to increase the strength and/or adhesion of the joints. Figure 1 presents an overview of compatibility degree of the thermoplastics have been tested as welding material with wood [5].



*Figure 1: Compatibility of thermoplastic materials in view of wood welding* 

#### Description and principle of WWT

A wood welding joint is very alike a glued joint in which the function of the adhesive is taken by the thermoplastic materials. The connection is mechanical but the anchorage with wood is improved as the fused thermoplastic pours into the porous cells of wood, what increases the surface of adhesion and creates a kind of root network.

# Advantages & disadvantages of WWT

With welding technologies, the energy is focused on the area which is to be joined, i.e. on the thermoplastic component. WWT show short time processes (short period in the clamp devices). They allow an industrial manufacturing on wood pieces integrally treated. WWT give repeatable and clean assembly (only "dry" materials are used). With welding joints, less mould working is required as not all the lengths of wood have to be fashioned. Welded dowels also show a good resistance to weather influences because of the density and connection of the thermoplastic at the wood surface.

On the other hand, fire resistance of welded joints is poor and special measures have to be taken to protect the thermoplastic from the heat. Another important aspect to consider today is the ecology of building components. Welded joints may show problem by the recycling phase and the elimination of this composite wood product may require the use of special installation.

# STATE OF ART OF TECHNOLOGIES

#### Ultrasonic (US) technology

The US technology allows to focus the energy where it is needed. This process is adapted to connect dowels and small surface joints. The energy, to fuse the thermoplastic material, is basically provided by the ultrasonic waves combined with pressure and speed. The process duration is set according to the masse of the thermoplastic. With US technology the

vibrations follow the axis formed by the welding column (Figure 2, [5]). The vibrations can be perpendicular (surface joints) or parallel (dowels) to the assembly elements.

Two groups of components formed the welding machine. The generator and the welding column which parts are the converter, the booster and the horn. The generator gives a constant electrical energy to the converter. The frequency is given by the electricity network (Switzerland: 50 Hz). The electrical energy is converted into a mechanical vibrations in the range of ultrasonic waves by a piezoelectric chipset located in the converter. These waves passes through the booster and the horn to finally be transmitted to the elements to be welded. The booster plays the role of the modulator of the vibration amplitude. The horn transfers the oscillations to the assembly elements, it may also allow the modulating of the amplitude of the waves. The welding column work in resonance.

The welding process is set up by the weld time, hold time, pressure and speed. A fine tuning of these parameters, according to a specific application, gives the most qualitative and economical result. A bad setting may cause a joint without resistance and/or burning spots in the joint.



Figure 2: Description and diagram of ultrasonic welding technology [5]

# Vibration welding technology

The vibration process is adapted to large connections. The energy to fuse the thermoplastic is produced by rubbing the pieces of the assembly together. The vibrations are parallel to the surface of the joint. The energy is function of the friction coefficient, the pressure and the type of the joint surface along with the amplitude, the frequency and the time.

Energy = force * distance	[E = Fs	in (J)]
Force = friction coefficient * pressure * surface	$[F = \mu p A$	in (N) ]
Distance= amplitude * frequency * time	[s = A f t]	in (m) ]

The vibrations can be linear or orbital depending on the geometry of the joint. The vibration machine is basically formed by a frame in which a mobile table is suspended on springs. The mobile part is put into vibrations with the response of tension of springs to an electromagnetic principle (Figure 3, [5]). The frequency can be 100 Hz with a maximum amplitude up to 4.0 mm, or 240 Hz and a maximum amplitude up to 1.8 mm. The machine set-ups are the welding time, the pressure, the amplitude and the hold time.



Figure 3: Description and diagrams of vibration welding technologies [5]

# Spin welding technology

The energy is, alike by vibration, created by rubbing the thermoplastic and wood together. This technology is limited in a certain range of applications with respect to the geometry of the connections, beside it is rather imprecise as final position of the thermoplastic part is difficult to control. It is however more simple to implement and requires less investment than the ultrasonic and vibration technologies.

With the spin process, the thermoplastic piece is spun against the wood elements. The quantity of energy is function of the time, the rotational speed and the pressure. Once the contact surface has melted, the piece of thermoplastic is hold still and some pressure is added until the assembly has cooled down.

# WWT RESEARCH PROJECTS AT SWOOD

# Fundamental research

It was in 1993 that SWOOD launched its first WWT project [1]. Basically the goal of this study was to investigate and perform new assembly methods for the window industry. To define the basic parameters, investigations were required to study the influences of the wood thickness with respect to energy transfer and of the reactivity of several types of lacquer.

The samples were an assembly of two pieces of lacquered wood and the lacquer was reactivated by US energy (Figure 4). Figure 5 presents the parameters and the criteria and Table 1 summarises the test series with respect to technical parameters and variables.



Figure 5: Parameters of test series and analysis criteria

Series	Wood species	Lacquer	Booster	Amplitude	Level	Repeating	Number	Var. parameters
I.1	beech	glacis	silver	62 µm	11	4	44	time & pressure
1.2	spruce	glacis	silver	62 µm	11	4	44	time & pressure
II.2	beech	lacquer	silver	62 µm	11	4	44	time & pressure
II.3	spruce	lacquer	silver	62 µm	11	4	44	time & pressure
11.4	spruce	glacis	gold	46 µm	5	4	20	time
II.5	spruce	glacis	green	46 µm	5	4	20	time

Table 1: Test series

A typical outcomes of the research is shown in Figure 6 which summarises the set-up of the US machine with respect to the pressure, the weld time and the strength of the joint. Figure 7 illustrates the interaction between the welding time and thickness of the piece of timber.





Figure 7: Welding time in function of wood thickness

# Fundamental study on welded thermoplastic dowels

The first project with this kind of connections was started in 1993 [1]. The investigations were conducted on thermoplastic dowels with the goal to find an optimal shape for the point of the dowels (Figure 8) and to test the strength of the anchorage regarding different drilling geometries. The dowels were welded parallel to the grain and tested in tension. Figure 8 presents the pulling out resistances of the dowels.



Figure 8: sample geometry (left), dowel geometry (centre), hole geometry (right)



Figure 8: Pulling out resistances

In summer 1999, investigations were conducted by SWOOD within the frame of a short term project [3]. The aim of this research was to get fundamental values of the strength of joints with thermoplastic dowels and to compare those with the ones of steel dowels. This study also intended to provide the necessary information to find industry partner in order to launch a larger research project in this field.



Figure 9: Principle of tests

The sample is an assembly of four dowels arranged in square according to the directives of the Swiss norm (SIA 164) – distance with the edges and distance between the dowels (Figure 9). Two thermoplastic materials and two dowel diameters were investigated. Figure 9 also gives details on the variable parameters of the experiments. It must be noted that only the wood lower part was un-drilled (Figure 10).

The dowels were embedded into it with the help of US energy and pressure – "molten nailing". The fine tuning of the welding parameters was achieved by screening.

The kind of connection is an adhesion as thermoplastic material filled the pores of the wood elements.



Figure 10: Assembly before welding (right), section of welded dowels perpendicular to grain (left)

The outcomes of these investigations showed promising results but further research is required to define the best thermoplastic or to improve the thermoplastic properties (reinforcement). Further, investigations must be done in order to optimise the joint geometry (geometry & repartition of dowels) and to get reliable values for the design. SWOOD has now reached the pre-phase of launching a more extensive research project and is in search of partner from the wood industry to comply with the Swiss Federal guidelines of the Commission of Innovation and Technology to get public support so that to be able to investigate further.



Figure 11: Diagram of the resistance in function of displacement (left), view of test installation (right)

# WWT: vibrations and spin technologies

In September 1999, a research project was launched with the aim to set the basic data of alternative welding technologies, such as the vibrations and spin processes, to the ultrasonic technology. This project is in progress. The investigations, that have already been done, have shown promising perspectives. An update of and further information on the project will be provided at the presentation at WCTE.

# Direct mandates with industry partners

Following the first research programs completed by SWOOD, industry partners of the wood industry showed interest to implement welding technologies. These mandates were mainly oriented toward the connection of window and door frames. SWOOD also got mandates from companies manufacturing furniture. Indeed WWT are very suited to joint porous material, thus it can provide optimal solutions for applications in an industry using many wood products such as particle and fibre boards.

#### APPLICATIONS OF WWT

Most investigations have been orientated toward jointing in industries of furniture and of doors and windows. These sectors potentially offered the best chances to WWT technologies. Eventually, partners from these areas showed the greatest interest and were ready to invest. Several development projects related to the processing are now under way.

WWT can find niches in wood construction and structure. Research in this field has only been launched lately. These investigations are needed on the thermoplastics with respect to the improvement of mechanical properties, and on the optimisation of the manufacturing. On one hand, machines able to weld large connections of trusses have to be developed and on another hand machines allowing small works at the workshop or on site have to be improved.

Further applications may also be workable with WWT. Thermoplastics may provide an optimal solution for connection of composite material, e.g. timber concrete composite. WWT may also offer an alternative to the traditional screws and nails by the fixing of wood lengths on concrete and terracotta bricks. The connection of the elements of stress-skin floors may be made with WWT avoiding the use of numerous mechanical connectors (nails, screws, etc.) or of glue. WWT may also be implemented for the finger jointing of lamellas e.g. glulam.

### CONCLUSION

The potential of WWT have not been exploited to the fullest now. Improvements of the strength of the thermoplastics are possible as well as the adhesion with wood. With its backgrounds with glues, SWOOD thinks that this can be achieve with additives. Ideally it would be to attain chemical connection by reactivating the hydroxyl group of wood with the thermoplastic.

The quality of the aesthetic aspect of the joint has also to be improved. The welding machine industry has performed significant improvements by using the latest technology for the machine control. These high-tech equipment may help to overcome the problems of the inhomogeneous properties of wood pieces.

Future research needs require a fine analysis at the molecular level between wood and thermoplastic when welded together. In cooperation with the Swiss Institute of Technology in Lausanne (EPFL), SWOOD is planning research in this direction.

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