

Plastic Coating of Plywood Using Extrusion Technique

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The target was to study and develop industrially suitable methods to apply thermoplastic coatings on plywood. Typically, wear and climatic resistance for wooden sheets, such as chip board and plywood, is achieved by thermosetting resin coating (e.g. phenol-formaldehyde). However, economical and environmental issues are driving towards thermoplastic coatings (e.g. polyethylene) in such products. Several technologies, such as film gluing and laminating, have been introduced, but the costs and processing are limiting factors. This study concentrates on direct coating of plywood with extruded molten plastic film, in other words extrusion coating of plywood. This technique provides fast coating process and cheap raw materials. In the study it was found that extrusion coating of plywood is difficult. The high heat energy of the molten plastic causes moisture evaporation of the top veneer, and the only possible escape direction of the evaporated moisture is through the plastic, which causes bubbling in the plastic coating. Another disadvantage of the plywood is its rigidity, which limits the development of the process. In this work, a new technique was applied for coating the flexible veneers with typical extrusion coating equipment, where the escape of the evaporated moisture was possible through the top veneer to the atmosphere. Another main issue was to reach sufficient adhesion between plastic and plywood. Target was achieved using either monolayer polyethylene (PE-LD) or 2-layer polypropylene/adhesion polymer plastic coatings.

Keywords plywood, thermoplastics, polymer, polyethylene, polypropylene, extrusion coating, adhesion

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1 Introduction

The target was to study and develop industrially suitable methods to apply thermoplastic coatings on plywood. Thermosetting resins, such as phenol-formaldehyde, are primarily used as coatings on top of plywood. However, environmental issues and limited properties are driving forces towards the use of thermoplastic coatings.

Coated plywood is primarily used in transportation vehicles and building industry. The main functions of coating on top of the wooden top veneer in plywood, are water (climatic) and wear resistance. The current coating materials are primarily thermosetting resins, such as phenol-formaldehyde (PF). The main disadvantages of coated thermosetting resins are: limited wear resistance, brown colour, limited colouring possibilities, and limited water resistance. On the other hand, thermoplastics, such as polyethylene (PE) and polypropylene (PP), provide typically much better performance, as far as wear and water resistance, and appearance (colouring) are concerned. (Tervala 1999).

Typically, films made of thermosetting resins are applied onto the plywood by pressing (high temperature and pressure). Other conventional coating methods are: gluing of plastic films, spraying of molten polymer, and lamination of films using heated rolls. Extrusion coating with thermoplastics onto plywood has also been utilised and also patented in *Menetelmä levymäisten ...* (1990) and *Järvelä* (1997). According to invented method *Menetelmä levymäisten ...* (1990), the extruded film is oxidised in the air gap between die and nip in order to improve adhesion between plastic and plywood. In patented method *Järvelä* (1997), the molten thermoplastic is applied directly under pressure onto the plywood, so that there is no air gap between die and plywood. (Tervala 1999).

Normal extrusion coating thermoplastics, such as polyolefins (polyethylene PE and polypropylene PP), are non-polar. Attraction between non-polar polyolefins and polar cellulose fibres (plywood top veneer) is weak due to their different molecular basis. Similar situation is found in extrusion coating of paper or paperboard. Adhesion characteristics in extrusion coating is widely studied and various adhesion promotion sys-

tems have been developed (Cramm and Bibee 1981, Gregory et al. 1982, Lindland and Peach 1985, Savolainen and Kuusipalo 1991, Siegel and Singer 1991, Antonov and Soutar 1991, Kuusipalo and Savolainen 1993, 1994, Kuusipalo 1997). Primers (solvent or water based adhesives) can be applied onto the paper surface prior to extrusion coating. Other typical pre-treatment methods, flame and corona treatments primarily oxidise the paper surface to make it more polar. Flame also heats and dries the web, which can also improve adhesion. In extrusion coating the extruded polymer film must also be oxidised in order to make it more polar to promote bonding to cellulose fibres. This is typically performed by allowing the oxidation of the hot polymer melt in the air gap between the die lips and nip. Other method to oxidise the polymer melt, is to blow induced ozone against the melt before nip.

Moisture content of top veneer depends on ambient relative humidity, as follows: relative humidity of 40–60 % corresponds to moisture content of 8–13 % in top veneer (Lemettinen et al. 1987). According to studies made by Tervala (1999), in extrusion coating of veneers, bubbling started not until the moisture content of the veneer exceeded 25–30 %. In this case, coating was carried out using the patented method (*Järvelä* 1997), where the coating is pressed directly onto the veneer. However, the moisture content (typically 6–10 %) of paper or paperboard is not typically a problem in extrusion coating, even if both sides of the paper is coated.

2 Experimental

Case 1

Fig. 1 illustrates the line used in the extrusion coating of plywood (Case 1). 2400 millimetres long and 100 mm wide plywood sheets were fed onto the supporting table where the drying was started with IR-heaters. The following nip, driven chill-roll and conveying belt provided constant line speed and support for the plywood sheets. Line speed varied from one to three metres per minute.

Drying was executed either by one or two identical IR-heaters, where the maximum power

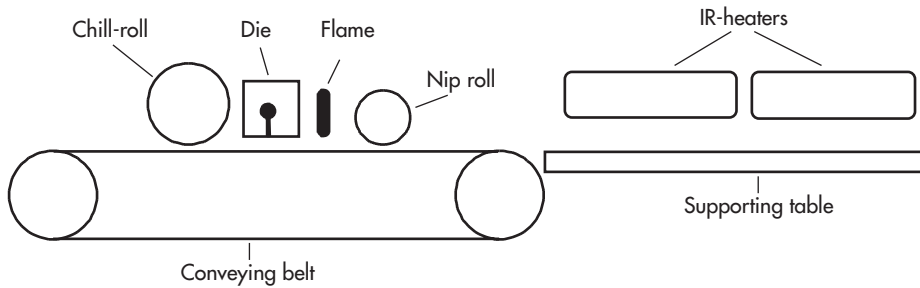


Fig. 1. Extrusion coating equipment for plywood in Case 1.

of 3.75 kW was used. The flame burner was located just before extrusion coating die and 20 mm above the plywood. In these experiments, fixed air/gas ratio was used to produce oxidising flame, because it causes more oxidation than normal or rich flame. Flame power was constant and adjusted to provide an optimal surface pre-treatment. Polyvinylidenechloride (PVDC) primer was either pre-dried or dried on-line by IR-heaters. Acrylate primer was always pre-dried. Extruded film from the die was cooled by the following chill-roll. Chill-roll temperature was 10 °C. The layer thickness of the polymer coating varied between 400–700 µm, depending on the line speed, output rate of the plastic and width of the coating.

It is very difficult, if not impossible, to utilise typical peeling tests (eg. T-peel) in evaluation of adhesion forces between the plastic coating and plywood/veneer. Because the coating thickness is high and the plywood/veneers are more less rigid, reliable adhesion test procedures are very hard to arrange. Also, in the case of fibre tear, peel tests are not useful, because actually the cohesive surface strength is measured, but not the adhesion force between the substrates. Typically, the bonding characteristics between plastic and paper is evaluated using certain criteria of how well the fibres are attached on the coating while peeled off from the paper. Therefore, analogue evaluation method was utilised in the case of plywood/veneers. In the method, the coatings were peeled of from the plywood/veneer using hands and the visual appearance of the attached fibres was evaluated. Table 1 shows the used bonding scaling of samples produced using

Table 1. The scaling of bonding used in Case 1.

Bonding value	Explanation
0	No adhesion
1	Weak adhesion, wood fibres not attached onto the peeled coating
2	Moderate adhesion, some fibres attached onto the peeled coating
3	Good adhesion, plenty of fibres attached onto the peeled coating
4	Very good adhesion, 100 % fibre tear when peeled off from the plywood

the case 1 extrusion coating procedure.

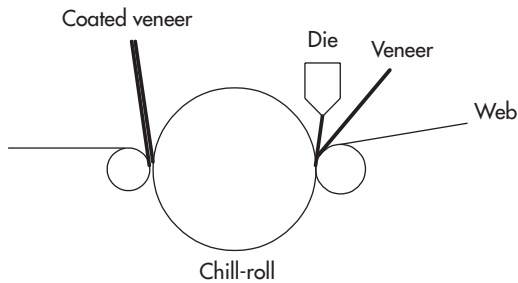
Because at least 5 tests per sample were evaluated, the average results are presented, as follows: 1+ stands for of about 1.25, 1...2 stands for of about 1.5, and 2- stands for of about 1.75, and so worth.

Case 2

The extrusion coating principle for the veneers is shown in Fig. 2 (Case 2). Coating was done using the pilot-coextrusion coating line, consisting of three extruders and a 350 mm wide 5-layer multimanifold vane die, located at the Institute of Paper Converting in Tampere University of Technology. Two extruders with typical PE-type screws were used. In the case of PE-LD coatings, both extruders were fed with PE-LD. On the other hand, in the case of coextrusion coating, polypropylene (PP) was fed in one ex-

Table 2. Extrusion coating polymers used in this study.

Polymer	Code	Grade	Manufacturer
Low density polyethylene	PE-LD	NCPE 1515	Borealis Polymers
Adhesion polymer	CXA	Bynel CXA E-129	Du Pont
Adhesion polymer	ADMER	Admer L-2000	Mitsui
Adhesion polymer	ER	–	–
Polypropylene	PP	PF 611	Himont

**Fig. 2.** Schematic illustration of extrusion coating equipment in Case 2.

truder and adhesion polymer in the other one. PP was extruded against the chill-roll and adhesion polymer against the veneer. Constants during the experiments were: chill roll (ϕ 600 mm) temperature 5 °C, die lip opening 0.5 mm, air gap 8 cm and nip (Shore-A 90) pressure 300 N/cm. Coating thickness was approximately 500 μ m.

Materials

Plywood and veneers were provided by Schumann Wood (currently UPM-Kymmene). Both birch and pine were used as top veneers in plywood and as separate veneers. Table 2 lists the polymers that were used as extrusion coating polymers.

3 Results

3.1 Case 1: Extrusion Coating of Plywood

Table 3 presents the parameters and results.

Bubbling of Coating Due to Moisture Evaporation from the Plywood

The influence of polymer melt temperature on the bubbling was obvious, the higher the melt temperature the higher the degree of bubbling. Clearly, the melt temperature of 315 °C is by far too high, whereas the melt temperature of 240 °C and below, is not causing too much bubbling. Only the application of PVDC-primer and its coating with CXA-polymer, caused bubbling at lower (240 °C) temperatures. Otherwise, there did not seem to be major differences in the degree of bubbling at lower temperatures, regardless of drying conditions, the use of flame, type of plywood (birch or pine) or the use of acrylate-primer. The rating of degree of bubbling was visual. Rather rough ratings were used due to lack of proper analysis method. Basically, degree of bubbling was rated, as follows: *none* = no bubbling, *some* = some bubbles, *much* = a lot of bubbling but not covering the whole coating area, and *very much* = practically the whole coating area filled with bubbles.

Adhesion between Plywood and Extrusion Coating Polymer

Clearly, the increasing melt temperature of PE-LD enhanced adhesion significantly. At 315 °C adhesion was sufficient (almost 100 % fibre tear),

Table 3. Extrusion coating of plywood using *Case 1* line: process parameters, adhesion and bubbling (type of plywood in column 1 means the type of top veneer of the plywood).

Type of plywood	Pre-primer	Pre-primer drying	IR-power (kW)	Flame	Polymer	Polymer melt temperature (degrees C)	Screw speed (rpm)	Line speed (m/min)	Bonding (0–4)	Degree of bubbling
Birch	Acrylate	Pre-dried	3.75	On	PE-LD	220	30	2	1–	none
Pine	Acrylate	Pre-dried	3.75	On	PE-LD	220	30	2	0...1	none
Birch	–	–	3.75	On	PE-LD	220	30	2	1+	none
Pine	–	–	3.75	–	PE-LD	240	30	2	2–	none
Pine	Acrylate	Pre-dried	3.75	On	PE-LD	240	30	2	1–	none
Pine	PVDC	Pre-dried	3.75	On	PE-LD	315	30	3	2+	much
Pine	PVDC	On-line	3.75	On	PE-LD	315	30	3	4–	much
Birch	PVDC	Pre-dried	3.75	On	PE-LD	315	30	3	4–	much
Birch	PVDC	On-line	3.75	On	PE-LD	315	30	3	4–	much
Birch	–	–	3.75	–	PE-LD	315	30	3	2...3	much
Birch	–	–	3.75	–	PE-LD	315	30	1.5	1+	very much
Birch	PVDC	Pre-dried	2 x 3.75	–	CXA	238	30	2	4–	much
Birch	PVDC	Pre-dried	2 x 3.75	On	CXA	238	20	2	4	some
Birch	PVDC	–	2 x 3.75	On	CXA	238	20	2	3–	some
Birch	PVDC	–	–	–	CXA	238	30	2	2...3	much
Pine	PVDC	Pre-dried	2 x 3.75	On	CXA	238	20	2	4–	much
Pine	–	–	–	–	CXA	238	20	2	1	much
Pine	PVDC	–	–	On	CXA	238	20	2	3+	much
Birch	Acrylate	Pre-dried	3.75	On	CXA	238	30	2	2–	none
Birch	Acrylate	Pre-dried	3.75	On	CXA	238	20	2	3–	none
Birch	Acrylate	Pre-dried	3.75	–	CXA	238	50	2	3–	none
Pine	Acrylate	Pre-dried	3.75	On	CXA	238	20	3	2+	none
Pine	Acrylate	Pre-dried	3.75	On	CXA	238	30	2	3–	none
Pine	Acrylate	Pre-dried	3.75	–	CXA	238	30	2	2+	none
Pine	Acrylate	Pre-dried	3.75	–	CXA	238	40	2	2...3	none
Pine	–	–	3.75	On	CXA	238	15	2	2–	none
Birch	Acrylate	Pre-dried	3.75	–	ADMER	220	30	2	1–	none
Birch	Acrylate	Pre-dried	3.75	On	ADMER	220	30	2	1–	none
Birch	–	–	3.75	–	ADMER	220	30	2	2–	none
Pine	Acrylate	Pre-dried	3.75	On	ADMER	220	30	2	1–	none
Pine	–	–	3.75	–	ADMER	220	30	2	1	none
Birch	Acrylate	Pre-dried	3.75	On	ER	220	30	2	1–	none
Pine	–	–	3.75	–	ER	220	30	2	2–	none
Pine	–	–	3.75	On	ER	220	30	2	2–	none

when using PVDC-primer. On the other hand, the increasing melt temperature did not improve adhesion between PE-LD and acrylate-primer. At lower (240 °C and below) temperatures, the adhesion was even in the best case only moderate.

As the different extrusion coating polymers are compared, PE-LD, ADMER and ER provided, roughly speaking, equal adhesion at similar conditions, and the adhesion was only moderate

in the best cases. Whereas CXA had, by far, the best adhesion of all, and especially with PVDC-primer. Unfortunately, as mentioned earlier on, PVDC-priming caused at each case bubbling of the coating. Typically, acrylate-primer provided adhesion changing from moderate to good. Furthermore, acrylate-priming did not cause any bubbling in the coating. The differences in bonding between birch and pine seemed to vary a lot: in some cases (similar conditions) pine provided

better bonding than birch, and vice versa. It is difficult to judge of which, pine or birch, provided better adhesion, because their surface strengths were not determined. However, the final result, which interests the end-user, is the plastic coating sufficiently adhered on the plywood, and in most cases the 100 % fibre tear indicates sufficient adhesion.

3.2 Case 2: Extrusion Coating of Veneer

Extrusion Coating of Veneer in Line 1 (Fig. 1)

Extrusion coating of veneers in line 1 was not successful as far as the bubbling of the coating is concerned. Several polymers, primers, melt temperatures (315 and 330 °C) and drying conditions were used, but the bubbling appeared almost at the same degree, as in the case of coating of the plywood (case 1).

Extrusion Coating of Veneer in Line 2 (Fig. 2)

Because of the bubbling at high melt temperature of 315 °C, a new idea was invented. The evaporation of the moisture inside the veneer could be removed in similar manner as in the case of extrusion coating of paper or paperboard by using a typical extrusion coating assembly (Fig. 2).

PE-LD was coated on top of the veneers at the melt temperatures of 320 °C and 335 °C. The outlook of the coating was excellent: it was clear and practically free from bubbles. Pre-dried veneer did not show any bubbling, and the non-dried veneers showed only very small bubbles (almost invisible), occasionally in the coating. Bonding was almost sufficient, some wood fibres were torn off and attached onto the coating while it was peeled off from the veneer. PVCD-primed veneers did not improve adhesion with PE-LD.

At the second step, PP/CXA coextruded film was coated onto the veneers, so that CXA adhesion polymer was against the veneer. Melt temperatures were 238 °C and 280 °C. Additionally PVDC-primer was applied onto the veneer and pre-dried before the coating. The coating quality

was very good, like in the case of PE-LD. The surface was harder than in the case of PE-LD, as expected. Adhesion was as good as in the case of PE-LD in both melt temperatures, thus the increase in temperature did not improve adhesion.

The disadvantage in the extrusion coating of veneer, is the warping of the veneer after it was coated. PP had clearly higher tendency to warp than PE-LD.

4 Summary and Discussion

Extrusion coating of plywood was not successful at melt temperature of 315 °C, because the humidity inside the plywood (top veneer) caused bubbling in the coating. In typical extrusion coating process, the water inside paper or paperboard can evaporate through the paper or paperboard to the atmosphere, when a very hot molten plastic is pressed against the fibrous web (paper or paperboard). On the other hand, in the case of plywood, the evaporated moisture cannot escape from the backside of the top veneer, because the alternating layers of veneers and phenol-formaldehyde resin prevent the free flow. The increased drying capacity (IR-heater and flame) did not prevent bubbling. It is evident that the top veneer should be totally dry at higher extrusion coating temperatures. At and below the melt temperature of 240 °C, the polymer coating hardly bubbled at all, probably due to lower initial heat energy and faster cooling. Adhesion was very good between PVDC-primed plywood and PE-LD (at 315 °C) in the areas, where the bubbling was not severe or was not present at all. At lower temperatures of 240 °C and below, the adhesion was rather good with CXA-polymer. PVDC-primer provided the best adhesion, but it caused bubbling also at the lower temperatures. In the case of PVDC-primer, it is possible that the primer itself functioned as a water vapour barrier, because PVCD is very good in that respect. Therefore, it might have performed as a barrier against the evaporated moisture in drying, and as the very high temperature PE-LD was coated on top of PVCD, the barrier was not any more sufficient to keep the moisture inside the top veneer, and thus, severe bubbling occurred.

Extrusion coating of veneer in line 1 showed almost as much bubbling as the coating of plywood. It was clearly observed, that the residence time of the molten polymer on the veneer was far too long before cooling, because there was plenty of time for the water inside the wood to evaporate and form bubbles in the coating. Thus, it is quite impossible to use line 1 construction at high melt temperatures without the formation of bubbles.

Extrusion coating of veneer in line 2 proved to be successful, as far as the bubbling of the coating is concerned. The rapid shock cooling and pressure (at the laminator nip) as the molten film hits the veneer, prevents the formation of bubbling in the coating, and still, a sufficient adhesion is formed between the polymer and the veneer. PVDC-primer is not needed in the case of PE-LD-coatings, however, it enhances the adhesion to CXA adhesion polymer coextruded along with PP, even at rather low melt temperature of 238 °C. PP has much higher warping tendency than PE-LD, because it typically post-crystallises (shrinks) after the coating procedure. Furthermore, the modulus of PP is higher than that of PE-LD (Kuusipalo 1997), which means that it has more susceptible to warp than PE-LD, in other words, as being more rigid, PP warps the veneer with greater force than soft PE-LD.

5 Conclusions

It is possible to achieve a good adhesion between typical thermoplastics (PE-LD and its copolymers) and plywood in extrusion coating. However, the obvious problem is bubbling of the coating due to evaporation of the moisture present in the top veneer. Naturally, it is possible to dry the plywood (and its top veneer) beforehand or even in-line. However, in pilot-scale even the in-line drying with quite powerful IR-heaters and flame treating unit did not remove the moisture sufficiently.

Extrusion coating of veneer caused similar bubbling problem as the coating of plywood, when the line construction was the same. This was due to long residence time of the molten polymer on top of the wood, which caused the evaporation of the moisture. On the other hand, typical extru-

sion coating equipment enable rapid cooling and subsequent solidification of the polymer, which prevents the formation of the bubbles. Furthermore, sufficient adhesion was achieved between the coating and the veneer both with monolayer (PE-LD) and 2-layer (PP/CXA) plastic coatings. The additional benefit of this technique is, that the line speeds can be very high. However, even though the veneers can be successfully coated with typical extrusion coating equipment, further technical work and improvements must be done in order to create a feasible system to manufacture plastic coated plywood products.

The area of this study is particularly interesting, because manufacturing technologies for products made of wood (furniture etc.) are currently widely studied. This is due to the fact, that some processes and materials, such as plywood coatings, paints and lacquers, do not necessarily meet either economical or environmental demands in future. The modification of wood surface is a challenging area of study.

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