

Characteristics Research about Coating System of Solventless Laminator

Lv Ling^{1,a}, Xu Wencai^{1,b}, Zuo Guangshen^{2,c}

¹Printing Equipment Engineering Research Center, Beijing Institute of Graphic Communication, 102600, Beijing, China

²Guangzhou Sinomech Corporation, 510830, Guangzhou, China

*Corresponding author Email: ^alvling19851@163.com, ^bxuwencai@bigc.edu.cn, ^czuoguangshen@126.com

Abstract: Coating system is the kernel of solventless laminator and the difficulty in the manufacture process. Precise control of coating weight (CW) is the key of solventless lamination, which restricts the development of solventless lamination, and the direct factors of making production achieve the best. Through the determination of CW, the various influence factors are determined. The technique and characteristics of solventless lamination are introduced. Structural characteristics about coating system and transfer discipline of solventless laminator are discussed. Through testing CW, transfer rules in the different speed ratios are analysed with the software of MATLAB. In accordance with coating inhomogeneity, the change of the viscosity of adhesive is the main factor. The basis to identify the quality of lamination products and know the right CW well are provided, which meet the coating requirements of solventless laminator.

Keywords: solventless lamination technique; coating system; CW; transfer rules; the viscosity of adhesive

1. Foreword

Solventless lamination is really a new technique of environment and health and can be widely used in flexible packaging industry. The interest of the field of lamination flexible packaging in food, medicine has been aroused. Today, solventless lamination technique can meet the requirements of 70%-80% of flexible packaging products, and has been widely used to produce laminating film^[1-3] internationally. In the actual production process, because of the low initial viscosity of solventless adhesive and the difficulty in the factor of operation control, besides, coating weight (CW is replaced below) in the unit area is very little, meanwhile, guarantee the stability and evenly adhesive coating, it's the difficulty of solventless lamination technique. Unstable coating can cause the adhesive coated unevenly, which influence the quality of products and restrict the development and application of solventless lamination technique. To control CW precisely is the key of solventless lamination and the requirement to enhance the products quality.

2. Solventless Lamination Technique

Solventless lamination is the technique that uses 100% solid of adhesive under the condition of heat and pressure to make two kinds of material into one lamination material. Solventless lamination technique mainly includes coating quality, coating accuracy, lamination effect and rewinding quality, in which, the precise design of coating system and the control of CW is the key factor which restricts the development of solventless laminator^[4].

Solventless lamination technique is simple, the area that equipment covered is small, and cost reduction, save resources, so it is the main development direction of lamination technique in the future.

3. Solventless Coating System

Solventless laminator mainly include two rewind devices, a wind device, a solventless adhesive coating system, a lamination device and a solventless adhesive supply device, and so on.

CW is very little, but requires solventless adhesive coated evenly on the material surface. Therefore, it should be a high precise coating system. According to the special structure of solventless adhesive, that its viscosity has a great change as long as the temperature changes, it is usually used with heated to make the viscosity decline for suitable coating. Therefore, solventless adhesive coating laminator is a special coating system with heating device^[5]. Solventless coating system usually uses four or five rollers structure, the installation precision and control requirements for parts processing are higher. The five rollers structure of coating system include metering roller, transfer steel roller, transfer rubber roller, coating steel roller and coating stress roller, as shown in Fig.2.

In coating system, there is a floating rubber roller device between the metering roller and the transfer steel roller. It can be used to eliminate the phenomenon that the friction between rollers will cause quantity of heat in a certain speed and temperature to protect the viscosity of adhesive and CW changing. Its metering roller and transfer steel roller are made of a group of chromium-plating rollers, between which there is a gap

that can be adjusted subtly. Adhesive is stored between the upper of the two rollers with a board blocked to maintain a certain liquid level. The metering roller corresponds to a scraping cutter, which is fixed and cleaned that direct manual control without stopping when necessary. Transfer rubber roller, transfer steel roller and coating steel roller are driven by servo motors respectively.

Five rollers coating system is suitable for the solventless adhesive whose viscosity ranges from 500cps to 10000cps and CW ranges from 0.5g/m^2 to 5g/m^2 . All five rollers are smooth rollers, including three steel rollers and two rubber rollers whose width are from 650mm to 1300mm. It only needs to adjust the gap and speed ratios among these rollers can achieve a ideal coating result^[6].

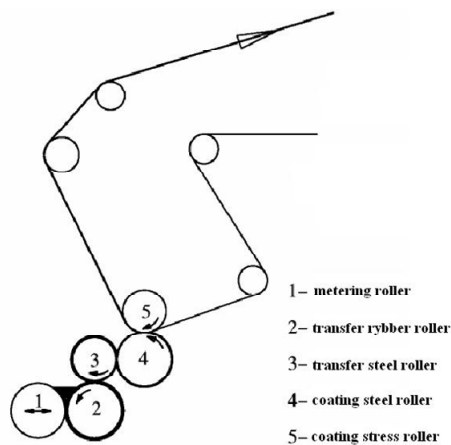


Figure 1. Five rollers structure of coating system.

4. Transfer Discipline

It's particularly important for solventless lamination to have the even coating thickness and enough CW. In the process of solventless lamination, CW of adhesive influences the quality of laminating film directly. According to the discipline of roller coating machine by Peter.J.Boss, CW mainly depends on the gap, speed ratio and pressure among transfer steel

roller, transfer rubber roller and coating steel roller. If CW is insufficient, it can lead to the adhesive peeled off or fall off easily because the adhesion strength of laminating film is too little. But if CW is excessive, it's also unfavorable for lamination and the cost of production will be increased.

In order to make the adhesive for coating formed a adhesive film on the surface of coating roller, transfer steel roller and transfer rubber roller must have different speeds, which are lower than that of coating steel roller. The speed of coating steel roller is equal to that of the machine. In coating system, there is a reasonable speed ratio among transfer steel roller, transfer rubber roller and coating steel roller (different models have different speed ratios). According to the sizes of the three rollers, a rotational speed ratio can be received, which is named the standard speed ratio. CW corresponding to the standard speed ratio is named the standard CW. The change of CW mainly depends on the speed ratio between the transfer steel roller and coating steel roller (i.e. that of the machine). Regardless of how changes the machine's speed, if only there is a certain ratio between the transfer steel roller and the machine, CW can be maintained in the required range. When CW is changed, the speed ratio between the transfer steel roller and the machine need to adjust as well as that of between the transfer rubber roller and the machine, which can be calculated according to the formula below:

$$i = \frac{q}{q_0} \times i_0 \quad (1)$$

where,

i - the speed ratio;

q - CW;

q_0 - the standard CW;

i_0 - the standard ratio^[7].

$$q = \left(\frac{q_0}{i_0} \right) \times i \quad \text{then,} \quad \text{CW} \quad (2)$$

Tab.1 Experimental Illustration

Experimental Principle	If the environmental conditions, adhesives, lamination material, gap, pressure and heating temperature are all defined, CW is related to the speed ratio between the transfer steel roller and the machine directly. In the actual production, it can be effectively controlled through adjusting the speed ratio of transfer steel roller.
Experimental equipment	SSL solventless laminator made in Guangzhou Sinomech Corporation
Experimental materials	OPP laminating film, Shanghai KANGDA solventless laminating adhesive
Testing instrument	Electronic Thickness Gauge
Experimental idea	Make laminating experiments with several reasonable speed ratios of transfer steel roller in a defined speed. Test the adhesive thickness of laminating film with different speed ratios after the experiment, i.e. CW test. Through the experiment, the linear relationship between CW and the speed ratio is received.

$$K = \frac{q_0}{i_0}$$

If making

then,

$$q = K \times i \quad (3)$$

So the relation between CW and the speed ratio is linear.

5. CW Test

5.1. Experiment

The density γ of coating adhesive can be calculated according to Formula(4):

$$\gamma = \frac{s}{1+s} \gamma_1 + \frac{1}{1+s} \gamma_2 \quad (4)$$

where,

γ_1 - 1.11g/CW³, the density of (Main agent);
 γ_2 - 0.975g/CW³, the density of (Curing agent);
 s- 100:75, the mixing ratio of (Main agent) and (Curing agent);
 γ - the density of adhesive after mixed. According to Formula (4), it is 1.0522g/CW³.

The thickness of coating adhesive is expressed as δ below:

$$\delta = \frac{q}{\gamma} \times 10^{-6} (m) \quad (5)$$

$$\text{then, } q = \delta \times \gamma (\mu m) \quad (6)$$

From Formula(4) to Formula(6), CW q (g/m²) can be tested through testing the thickness of adhesive δ (μ m).

Tab.2 CW Test with Different Speed Ratios of Transfer Steel Roller

Test	Speed Ratio of Transfer Steel Roller	Single Film Thickness of OPP ($\times 2$) / μ m	Thickness Lamination Film of OPP/OPP / μ m	Adhesive Thickness / μ m	CW q (g/m ²)
1	8%	41.0	41.8	0.8	0.92
2	12%	41.0	42.0	1.0	1.05
3	16%	41.0	42.3	1.3	1.37
4	20%	41.0	43.1	2.1	2.22
5	24%	41.0	43.4	2.4	2.56

5.2 Data Analysis

The linear mathematical model between CW and the speed ratio was established as:

$$q = a_1 + a_2 \times i$$

(a_1, a_2 are undetermined coefficients)

$$\begin{bmatrix} q_1 \\ q_2 \\ q_3 \\ q_4 \\ q_5 \end{bmatrix} = \begin{bmatrix} i_{1,1} \\ i_{2,1} \\ i_{3,1} \\ i_{4,1} \\ i_{5,1} \end{bmatrix} \times \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

Matrix form was

Experimental datas were made a linear fitting optimization through the software of MATLAB, a mathematical tool, and the undetermined coefficients of fitting model were calculated by using the least-square method. MATLAB program is described as follows:

```
i=[0.08,0.12,0.16,0.20,0.24]';
```

```
q=[0.92,1.05,1.37,2.22,2.56]';
```

```
X=[ones(size(i)),i];
```

```
a=X\q
```

```
T=[0:0.01:0.25]';
```

```
Y=[ones(size(T)),T]*a;
```

```
plot(i,q,'▲')
```

```
grid
```

Operation results: $a = -0.1560$

11.1250

i.e. $a_1 = -0.156, a_2 = 11.125$

Linear fitting curve was showed as Fig.3:

The linear relationship between CW and the speed

ratio is:

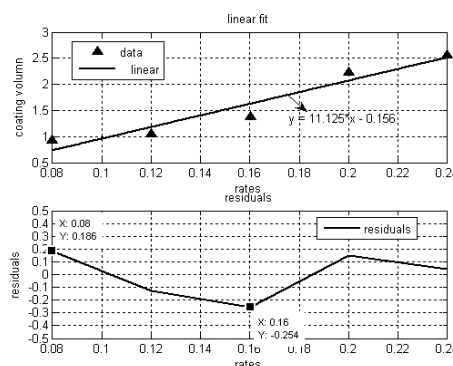


Fig.2 Fitting results and fitting residual curve

$$q = 11.125 \times i - 0.156 \quad (7)$$

Generally, CW of solventless laminating adhesive ranges from 0.5g/m² to 3.0g/m², then according to different coating requirements, the adjusting range of speed ratio of transfer steel roller is (6%-30%). The best choice for CW is made a comprehensive consideration according to different quality requirements, film properties, printing results and performances of printing ink and adhesive.

If CW is allowed the error less than (± 1 g/m²), the linear relationships can be expressed as

$$q = 10 \times i \quad (8)$$

roll speed ratio and CW.

6. Influence Factors of Coating Transfer

6.1. Coating Inhomogeneity

Through the coating weight of the test results also showed that the same experimental parameters, as shown in Figure 4 in the laminating film of non-complex 1-5 to take the direction of the average coating weight for different parts of the measurement.

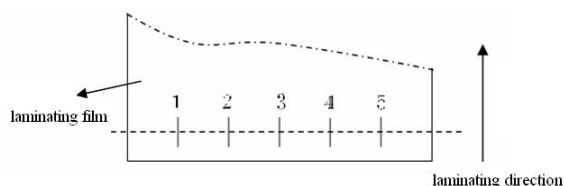


Figure 3. Test schemes.

Test results indicate that CW is different in the same experimental parameters, which reflects coating inhomogeneity. In Figure 5, CW when the speed ratio of transfer steel roller is 10% is analyzed. The median line of fluctuation represents the average value of CW.

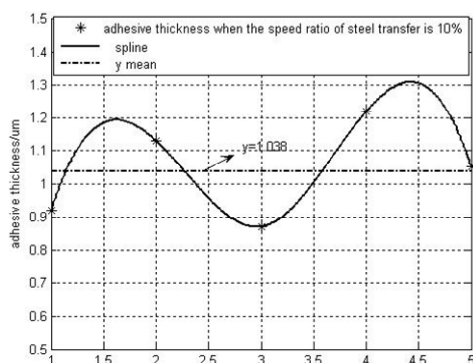


Figure 4. transfer speed ratio of 10% for steel roller coating.

6.2 Solventless Polyurethane Adhesive

CW error and coating inhomogeneity reflect the inconsistent coating thickness, in the other words, adhesive is transferred instability.

As mentioned above, the speed ratio, the gap and the pressure among transfer steel roller, transfer rubber roller and coating steel roller are the factors which affect CW directly. In addition, CW is related to other factors, such as: brand and model of adhesive (it's mainly viscosity and mixing ratio), machine speed, coating conditions, printing substrate and printing images (it's mainly the transfer speed ratio and inhomogeneity), etc., in which the change of adhesive viscosity is the main factor.

In solventless lamination, solventless two-component polyurethane adhesive is used commonly. The attraction between molecules of

solventless polyurethane adhesive is large (it can form hydrogen bonds), which makes it seriously affected by temperature^[8-9]. The viscosity - time and temperature - time graph about German Bostik at 20°C are shown in Fig. 6. It is shown that the temperature of adhesive will enlarge with the time passes, meanwhile, its viscosity will increase with the temperature enlarges.

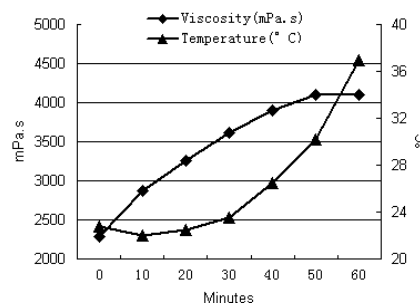


Figure 5. Bostik 20 °C, the viscosity - time and temperature - time graph.

One hand, the change of adhesive's viscosity will cause the CW changing, coating insufficient, laminating layer curing uncompletely and accidents happen easily when heated in the heat sealing layer; the other hand, it will make the transfer state deteriorate gradually, the transparency and smoothness of coating film down, or even "adhesive point" or "orange peel-like" and other failures. The lower viscosity is, the more CW is transferred; the higher viscosity is, the little CW is transferred. Coating quality defects lead to inconsistent coating thickness, coating uneven, coating surface roughness, and many other issues^[10].

6.3. Suggestions for Improvement

To obtain the CW, we must consider the factors above fully, which can correct and analysis quality problems because the CW is transferred instably.

1、Adhesive viscosity is affected easily by coating environmental, so to ensure a good environment, these coating systems should be considered:

a. dehumidification installation: in addition to the workshops, the relative humidity of the adhesive storeroom should be controlled as low as possible. The dehumidification equipment in the coating device would make the coating system dry and filter completely;

b. thermostat: because the viscosity of solventless adhesive is sensitive to temperature, this installation can make the temperature drop to the right coating temperature through heating. It also can determine the optimum coating temperature and maintain the minimum difference in temperature;

c. suction installation: in preparation for the problem that a lot of air will be mixed when compounding

adhesive, the cycle suction system can be designed and installed. One hand it's not necessary to use the mode of dumping which can reduce the mixed air, the other hand it can also take the mixed air out to ensure uniform adhesive coating.

2、These conditions below will lead the viscosity of adhesive to rise:

1) When the adhesive has been compounded and poured into the trough, the equipment stops because of various reasons; 2) Speed of the equipment is too slow.

Suggestions for improvement below:

a. prepare the Zahn viscosity cup and hygrometer to measure the viscosity of adhesive. Measure the viscosity of adhesive regularly and master the different changing conditions of temperature and humidity about the viscosity of adhesive;

b. consider workshop transformed to constant temperature and humidity workshop;

c. minimize the air contact area between the barrel and trough, such as with cover;

d. do preparatory work well before laminating to minimize the stopping time;

e. use maximum operating speed of the equipment if allowed.

Currently, most domestic manufacturers who product laminating film use dry laminating process to product film, which makes a little of solvent residues and leads to peculiar smell and poor sanitation performance of the packaging^[11]. There is not solvent within solventless adhesive, so laminating film products will not pollute content of the packaging material because of the residual solvent. That replace dry lamination by solventless lamination have a clear advantage in terms of environmental protection and low-carbon, production

and food safety, product quality. Especially in terms of lower production costs and economic benefits increasing, it has a remarkable results, which has a great significance regardless of both involving in the fierce market competition and obtaining more profitable for companies^[12].

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