Use of novel synthesized aqueous binders for pigment printing of polyester fabrics

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A variety of new synthesized polyurethane acrylate polymers has been used as textile binder in the pigment printing for screen printing of polyester fabrics and for pigment fixation through polymerization process for binders by using thermo fixation as well as radiation curing (UV and microwave) fixation modes. The effects of change in temperature of thermo fixation and the time of curing in both UV and microwave with the concentration of prepared binders in printing paste on the color strength, and prints fastness properties are studied. The newly synthesized polyurethane acrylate binders could be successfully used for pigment printing of polyester fabrics using three fixation modes and, in general, their prints possess color strength value comparable or even higher to those obtained upon using selected commercial binder.

Keywords: Aqueous binders, Microwave curing, Silk screen printing, Thermo fixation, Polyurethane acrylate, Polyester fabrics, Pigment printing, UV curing

1 Introduction

Pigment printing is perhaps the most commonly and extensively used technique for printing textiles due to its obvious advantages\(^1\),\(^2\), such as versatility, ease of near final print at the printing stage itself, applicability to almost every kind of fibre or mixture, and the ability to avoid any washing processes after fixation\(^1\). However, pigment printing has a few problems, such as relatively high curing temperature, stiff hand and poor crock fastness of printed goods. These disadvantages are related to binder used. Thus, to improve the quality of pigment goods, the overall properties of the binders need to be improved. Methods to lower the curing temperature have received the most attention because the high temperature cure process not only wastes energy but also creates the risk of destroying substrates that cannot endure high temperature processes. Radiation curing technologies (UV and microwave) are used in many industrial applications as well as in the textile area\(^1\), because of low energy consumption, short start-up period, fast and reliable curing, low environmental pollution, fixation at room temperature, space saving, etc.

Microwave irradiation is a well-known method for heating and drying materials and is utilized in many private households and industrial applications.

It offers a number of advantages over conventional heating, such as noncontact heating (circumventing the decomposition of molecules close to the walls of the reaction vessel), instantaneous and rapid heating (resulting in a uniform heating of the reaction liquor), and highly specific heating (with the material selectivity emerging from the wavelength of microwave irradiation that intrinsically excites dipolar oscillation and induces ionic conduction)\(^5\).

The present study is aimed at investigating the use of the synthesized aqueous polyurethane acrylate as binders having zero volatile organic emissions (aqueous binders) based on polyethylene glycol with different molecular weights and polyol mixtures, in pigment printing of polyester fabrics using silk screen technique, and in pigment fixation through the polymerization process of the binder by using the thermo fixation mode, and the newly adopted UV and microwave techniques.

2 Materials and Methods

2.1 Materials

100% polyester knitted fabric of 150 g/m\(^2\), supplied by a private sector was used. Bercolin Red B3E pigment, supplied by Berssa Co., Turkey, was used. Ammonium per sulfate [(NH\(_4\))]\(_2\)S\(_2\)O\(_8\)], supplied by Merck, Germany, was used as a thermal initiator. Esacure DP 250, supplied by Lamberti Spa, Italy, was used as photo initiator. Bercolin CPK, supplied by Berssa, Turkey, was used as thickening agents.
The different aqueous polyurethane acrylate, synthesized\(^6\) based on polyethylene glycol with different molecular weights and polyol mixtures, were used as binders. The first four binders based on isophoron diisocyanate are shown below:

- **Binder 1** —poly urethane acrylate (PUA) based on poly ethylene glycol (PEG) 6000 g/mol + polyl + hydroxy ethyl acrylate (HEA).
- **Binder 2** —poly urethane acrylate (PUA) based on poly ethylene glycol (PEG) 12000 g/mol + polyl + hydroxy ethyl acrylate (HEA).
- **Binder 3** — poly urethane acrylate (PUA) based on poly ethylene glycol (PEG) 20000 g/mol + Polyl + hydroxy ethyl acrylate (HEA).
- **Binder 4** — poly urethane acrylate (PUA) based on poly ethylene glycol (PEG) 20000 g/mol + polyl + hydroxy propyl metha acrylate (HPMA).

The last three binders based on toluene diisocyanate are given below:

- **Binder 5** — poly urethane acrylate (PUA) based on poly ethylene glycol (PEG) 20000 g/mol + polyl + hydroxy ethyl acrylate (HEA).
- **Binder 6** —poly urethane acrylate (PUA) based on poly ethylene glycol (PEG) 20000 g/mol + polyl + hydroxy propyl metha acrylate (HPMA).
- **Binder 7** — poly urethane acrylate (PUA) based on poly ethylene glycol (PEG) 6000 g/mol + polyl + hydroxy propyl metha acrylate (HPMA).

Two different commercial binders used were: (i) Bercolin metal CM (thermal curing binder) supplied by Berssa, Turkey, and (ii) Ebecryl 2001 (radiation curing binder) supplied by Surface Specialties UCB, Belgium.

### 2.2 Methods

#### 2.2.1 Preparation of Printing Pastes

The pigment printing pastes were prepared according to the following recipe:

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pigment</td>
<td>50 g</td>
</tr>
<tr>
<td>Binder</td>
<td>1, 2, 3 and 4%</td>
</tr>
<tr>
<td>Thickener</td>
<td>40 g</td>
</tr>
<tr>
<td>Initiator</td>
<td>10 g</td>
</tr>
<tr>
<td>Distilled water</td>
<td>1000 g</td>
</tr>
</tbody>
</table>

The initiators used were either thermal initiator (ammonium per sulfate) or photo initiator (Esacure DP250).

#### 2.2.2 Printing Techniques

Two printing pastes containing the thermal initiator or UV curing photo initiator, in addition to the other ingredients, were prepared. The homogenized printing pastes were applied to the fabrics using a flat screen technique.

### 2.2.3 Pigment Fixation

The samples printed with the thermal paste (using thermal initiator) were thermo fixed at different temperatures (80, 100, 120 and 160 °C) for a period of 4 min, while the samples printed with the pastes including the photo initiator were either fixed using UV rays at wave length 254 nm for 3, 5, and 10 min or using microwave oven at 500 watt for 3, 4 and 5 min.

### 2.3 Measurements and Analysis

The relative colour strength of the prints (K/S value)\(^7\) of the coloured samples was determined by reflection measurements using data colour international model SF 500, USA.


### 3 Results and Discussion

The difference between dyeing processes and pigmentation is that the pigment colored textiles requires a curing procedure. Since pigments do not have an affinity to textiles, pigment fixation on textiles relies on binders that require a curing process to hold the pigments on a textile. Conventional curing is a thermal process where pigment colored textiles must be dried and then cured with heat to convert the soft organic base (monomer and/or oligomers) to a tough polymer\(^4\).

The aim of this paper is to investigate the possibility of using the prepared polyurethane acrylate polymers based on poly ethylene glycol (PEG) with different molecular weights and polyl mixtures as binders for pigment printing of polyester fabrics, using silk screen techniques. The results are compared with those obtained when a commercial binder is used in every case under similar conditions. Fixation of the prints is achieved via thermo fixation (conventional method) as well as via UV and microwave techniques.

In thermo fixation technique the corsslinking reaction is initiated by thermal decomposition of the per sulphate groups to produce sulphate ion radicals alone with their radical species. The radicals formed in this way are used as initiators for the cross-linking reaction. The mechanism of free radical generation reaction is shown in Scheme 1(ref 8).
Thus, the acrylate terminal double bond polymerization can be initiated by either the SO\textsubscript{4}\textsuperscript{2-} or by \textsuperscript{’}OH radicals. In the presence of polyurethane acrylate, these free radicals can attack polyurethane at terminal ends (double bond), thereby forming macro radicals capable of initiating the crosslinking reaction (crosslinking polymerization of the polyurethane). Radiation curing is an alternative to the thermal process. Radiation curing resin formulations contain monomers, and photo initiators. These components can be polymerized (hardened) by the free radical mechanism as shown in Scheme 2 (ref. 9).

The free radical generated by mean of high energy radiation\textsuperscript{10-12} is shown in the Scheme 3. Use of a photo initiator triggers a nearly instantaneous curing reaction upon exposure to UV light.

Thus, UV curing produces a completely polymerized network in seconds which is faster than thermal curing\textsuperscript{13}. After the free radicals are generated, the polymerization reaction occurs as shown in Scheme 4.

### 3.1 Effect of Experimental Parameters on Color Strength

#### 3.1.1 Effect of Fixation Temperature, Binder Type and Binder Concentration

In the first stage of the investigation, the prepared pigment pastes, containing 5% Bercolin Red B3E, and different concentrations (1, 2, 3, and 4 %) of the synthesized polyurethane acrylate (binders b1-b7), as well as the commercial binder (thermal type) were applied on polyester fabrics by the flat silk screen technique. The printed samples were dried and then thermally polymerized with hot air at different fixation temperatures (80, 100, 120, and 160 °C) for 4 min. Figure 1 shows the effect of different concentrations of polyurethane acrylate (binders b1-b7) as well as Bercolin Red B3E in the printing process. The color strength of pigment printed polyester fabric (K/S) was measured and compared with the commercial binder (co).

![Scheme 1 — Mechanism of radical generation via thermal initiation](image1)

![Scheme 2 — Formulation of photocurable system](image2)

![Scheme 3 — Generation of free radical via photo initiation](image3)

![Scheme 4 — Mechanism of radical polymerization](image4)

![Figure 1 — Effect of fixation temperature (80, 100, 120, and 160 °C) and type of binder (synthesized binders b1-b7 and commercial binder co) and their concentration (1, 2, 3, and 4%) on the color strength of pigment printed polyester fabric](image5)
paste formulation on the color strength of screen printed and thermally cured polyester fabrics for 4 min, as compared to that of commercial binder.

Figure 1 shows the effect of afore-mentioned different binders concentrations on the color strength of the printed polyester fabrics thermally cured under the above conditions. It is observed that the color strength of printed polyester fabric depends mainly on binders type and more or less on binders concentration as well as the fixation temperature. It can be seen that upon using binder concentration of 1% and 2% in the printing paste, they produce comparable color strength results. Further increase in the binder concentration up to 4% produces no significant color enhancement and therefore it is not recommended to use more binder concentration except in case of using the commercial binder. Prepared binders in the pastes produce polyester printed samples with higher color strength values in most cases, as compared to the commercial binder (Bercolin metal CM) at low temperature under the same conditions. It is also clear from Fig. 1 the binders b1, b3 & b6 are the best binders in this set and give a good color strength values at lower binder concentration. A more complete polymerization can be achieved by rising the fixation temperature. This explains the further increase in color strength of the printed fabric by gradual rise in fixation temperature until 160°C (Fig. 1). The synthesized binders give better $K/S$ values at lower fixation temperatures than the commercial binder which gives acceptable $K/S$ results only at higher fixation temperature. This may be due to the occurrence of polymerization reaction at acceptable rate at lower temperature in case of synthesized binders, which is reverse in case of commercial (thermally cured) binder. A commercial binder needs higher temperature to obtain good polymerization rate which affects the economical aspects of the process. Generally, as shown in Fig. 1, the binders b1, b3 & b6 appear to produce printed samples with highest color strength values as compared to the results obtained by the commercial binder and the remaining binders (b2, b4, b5 & b7). This could be attributed to the presence of higher amount of unsaturated groups during the synthesis process. Subsequently, the increase in the amount of unsaturated groups increases the binder polymerization which results in better pigment fixation. The synthesized binders give better $K/S$ values at lower fixation temperatures and lower binder concentration than those obtained on using commercial binder, which gives acceptable $K/S$ results only at higher fixation temperature (160°C) and at higher concentration. Fixation temperature of around 160°C could be recommended for all synthesized binders at 1% binder concentration and 4 min time of fixation.

3.1.2 Effect of UV Fixation Time, Binder Type and Binder Concentration

Pigment printing cured via irradiation (UV & microwave) eliminates the drying step and greatly reduces the energy required for curing. High curing speed, high cross-linking densities and the absence of organic solvents have made radiation curing a well-established technology for all kinds of coating and ink applications.

Today numerous UV-curable monomers and polyether, polyester, epoxy, polyacrylate and urethane acrylates are available in the market. By the choice of raw materials, such as binders and accompanying monomers, and photo initiators, the film properties such as hardness, flexibility, resistance and adhesion can be controlled in a very flexible way. Acrylic monomers do not absorb UV-light in a very efficient way and do not initiate radical polymerization fast enough. As such, a photo polymerisable film forming formulation essentially consists of a polymerisable vehicle and a light sensitive compound that is able to convert the absorbed light energy into a more useful form, capable of causing the binder to polymerize into a hard solid mass.

Such a light sensitive compound is known as photo initiator/ sensitizer. Thus, a photo initiator is added to produce initiator free radicals directly by the fragmentation of the photo-excited state; these free radicals are capable of initiating the polymerization reaction.

Photo initiator is of paramount importance in radiation curable systems. A photo initiator is selective in terms of light of specific wavelengths. During formulation, the absorbency characteristics of the photo initiator are matched to the radiation characteristics of the lamp output. Indeed, the choice of photo initiator is of prime impotence in the light induced polymerization since it directly governs the cure rate.

Different pigment pastes containing 4% Bercolin Red B3E pigment, and different concentrations (1 and 4%) of the synthesized polyurethane acrylate binders (b1-b7), as well as the commercial binder Ebecryl 2001 and the photo initiator Esacure DP 250 were applied on polyester fabrics by the flat screen technique, dried and then subjected to UV curing for different intervals of time (3, 5 and 10 min). The results are shown in Fig. 2. Pigment fixation on
polyester fabrics by polymerization of the binder via present unsaturated groups when subjected to UV curing rays is expected. It is clear from Fig. 2 that the type of binders used in this case has a very pronounced effect. The UV cured printed samples with elevated $K/S$ values are obtained with printing pastes containing binders b1, b4, b6 & b7 as compared to those containing the commercial binder and binders b2, b3 & b5. This is true irrespective of the binder concentration and the time of UV curing fixation. These results may be attributed, as mentioned before, to the difference in binder structure as well as the presence of the unsaturation groups. Binders b1, b4, b6 & b7 are also characterized by high contents of these groups, which are responsible for the binder polymerization and pigment fixation upon curing.

It could be concluded that the presence of 1% polyurethane acrylate binder in the polyester pigment printing paste, and curing time of 3 min by UV rays could be considered as optimum conditions.

### 3.1.3 Effect of Microwave Fixation Time, Binder Type and Binder Concentration

Different pigment pastes containing 4% Bercolin Red B3E pigment, different concentrations (1 and 4%) of the synthesized polyurethane acrylate binders (b1-b7), as well as the commercial binder Ebecryl 2001 and the photo initiator Esacure DP 250 were applied on polyester fabrics by the flat screen technique. The samples were then introduced into microwave oven as it is wet without drying step, and subjected to microwave curing for different interval of times (2, 3, and 4 min), keeping the operating power at 500 w. The results are given in Fig. 3. The binders (b1-b7) contain some unsaturated groups, which under the effect of microwave can undergo a polymerization reaction, leading ultimately to pigment fixation on the polyester fabrics. The results also show that the type of binder derivative used in this case has a very pronounced effect. Also it can be seen that microwave cured printed samples with elevated $K/S$ values are obtained with printing pastes containing binders b1, b6 & b7 as compared to those containing the binders, b4, b3, b2 and b5. This is true irrespective of the binder concentration and the time of microwave curing fixation. These results may be attributed, as mentioned before, to the difference in binder structure as well as the presence of unsaturated groups. Binders b1, b3, b4, b6 and b7 are characterized by higher unsaturated groups, which are responsible for the polymerization and pigment fixation upon curing. The materials that absorb microwave radiation are called dielectrics, and hence microwave heating is also referred to dielectric heating. The interaction of dielectric materials with electromagnetic radiation in the microwave range results in energy absorbance. The ability of material to absorb energy while in a microwave cavity is related to the loss tangent of material\(^2\). It is observed from Fig. 3 that curing time does not affect the color strength of the prints, irrespective of binder type or its concentration.

### 3.1.4 Effect of Mode of Fixation

The color strength results obtained by thermal, UV and microwave fixation techniques for screen printed polyester fabrics with pigment paste containing 4% Bercolin Red B3E pigment and 1% binder (binders b1-b7) and with commercial binders are shown in Fig. 4.
The results show that under the selected thermal fixation conditions of 160 °C & 4 min, UV curing conditions of 5 min, and microwave curing of 2 min, the thermo fixed printed samples possess higher color strength values when compared with the corresponding UV and microwave cured printed samples upon using synthesized binders. The highest $K/S$ is obtained with binders b1 & b6 in case of either thermo or microwave fixed printed polyester samples. It is clear that the $K/S$ values of printed samples with pastes containing the synthesized binders and cured by using UV and microwave techniques are higher than the printed samples using commercial binder in its pasts and fixed by the same techniques. Generally, the highest $K/S$ values are observed for radiation curing (UV) in case of binders b4 & b6.

3.2 Fastness Properties

Since pigment printing using thermal curing, UV curing and microwaves curing is a surface application, the major concern is the abrasion resistance of the printed fabrics either towards washing or rubbing. In thermal curing process, the crosslinking is essential for the adhesion of the binder to the textile surface and to give the pigment prints optimum fastness properties. Applying high curing temperature to fix the pigment colors, as much as needed is an unfavorable printing aspect. This not only wastes the energy but also creates the risk of the thermo degradation of substrates. In UV curing, these risks are however minimized.

Table 1 shows the color strength and overall fastness properties of screen printed and thermally
cured (at 160°C for 3min) polyester fabrics treated with pigment printing pastes containing 1% polyurethane acrylate binders (b1-b7), and 5% Bercolin Red B3E pigment, including those obtained upon using the commercial binder (Bercolin metal CM) respectively. The results show that both the color strength and the fastness properties of the printed samples depend on the type of binder used. Prepared binders show much higher color strength results as compared to commercial binder under the same conditions. The rub fastness results are acceptable for thermally cured polyester printed samples, but improvement is noticed with binders b1, b2, b4, b5 & b6 as compared to those obtained with binders b3, b7 and the commercial binder. The rub fastness is found to be good to very good in case of binders b1, b2, b4, b5, b6 and commercial binder; and moderate to good in case of binders b3 & b7. Moreover, wash and perspiration fastness properties are in the range of very good to excellent for fabric printed using the prepared binders in the printed pastes.

Table 1— Overall fastness properties of pigment printed and thermally fixed polyester fabric using prepared and commercial binders

<table>
<thead>
<tr>
<th>Binder</th>
<th>K/S Dry</th>
<th>Rub fastness</th>
<th>Wash fastness</th>
<th>Perspiration fastness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>St.</td>
<td>Alt.</td>
<td>St.</td>
<td>Alt.</td>
</tr>
<tr>
<td>Commercial binder</td>
<td>2.8</td>
<td>3</td>
<td>4-5</td>
<td>4</td>
</tr>
<tr>
<td>(co)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Binder 1 (b1)</td>
<td>11.5</td>
<td>3</td>
<td>4-5</td>
<td>4</td>
</tr>
<tr>
<td>Binder 2 (b2)</td>
<td>3</td>
<td>3-4</td>
<td>4-5</td>
<td>4</td>
</tr>
<tr>
<td>Binder 3 (b3)</td>
<td>8.8</td>
<td>2-3</td>
<td>4-5</td>
<td>4</td>
</tr>
<tr>
<td>Binder 4 (b4)</td>
<td>9.2</td>
<td>2-3</td>
<td>4-5</td>
<td>4</td>
</tr>
<tr>
<td>Binder 5 (b5)</td>
<td>11.8</td>
<td>3</td>
<td>4-5</td>
<td>4</td>
</tr>
<tr>
<td>Binder 6 (b6)</td>
<td>10.1</td>
<td>3</td>
<td>4-5</td>
<td>4</td>
</tr>
<tr>
<td>Binder 7 (b7)</td>
<td>8</td>
<td>2-3</td>
<td>4-5</td>
<td>4</td>
</tr>
</tbody>
</table>

St. — Staining; Alt. — Alteration.

The roughness properties are observed for screen printed polyester using printing pastes containing 4% Bercolin Red B3E, 1% synthesized polyurethane acrylate binders (b1-b7), as well as the commercial binder (Bercolin metal CM) and thermally cured at 160°C for 4min. The results show that the roughness for both printed fabrics depends on the type of binder used. The commercial binder shows higher roughness results (22.4) than those obtained by synthesized binders (b1= 18, b2= 19.3, b3= 12, b4= 13.1, b5 = 15.8, b6 = 8.9 and b7= 9.91).

Table 2 shows the color strength and overall fastness properties of screen printed and UV cured (3 min) polyester fabrics using pigment printing pastes containing 1% polyurethane acrylate binders (b1-b7), and 5% Bercolin Red B3E pigment, as well as the commercial binder (Ebecryl 2001) respectively. The results show that the fastness properties of the printed samples depend slightly on the type of binder used. Binders b1, b4, b6 & b7 show much higher color strength results as compared to binders b1, b2, b5 and the commercial binder.

The results show that the rub fastness ranges from good to very good in case of using the binders b1, b3, b4, b5, and commercial binder and ranges from moderate to good in case of using binders b2, b6 & b7. Moreover, wash and perspiration fastness properties are in the range of very good to excellent for fabric printed using the prepared binders in the printed pastes.

The roughness properties are observed for screen printed polyester fabrics, using printing pastes containing 4% Bercolin Red B3E, 1% synthesized polyurethane acrylate binders (b1-b7), as well as the commercial binder and UV cured for 5min at 254nm wavelength. The results show that the roughness of printed fabrics depends on the type of binder used. Binders b1, b3 & b7 show high roughness results compared to commercial binder (commercial binder = 18.1, b1= 18.6, b2= 17.4, b3= 18.5, b4= 18.11, b5 = 17.6, b6 = 13.8 and b7= 20.9).
type of binder used. It could be noticed that the rub fastness results improve for printed samples, upon using all the aforementioned synthesized polyurethane acrylate binders and microwave curing technique as compared to those obtained by the traditional thermals curing technique. Some improvement is noticed with binders b2, b4, b5, b6 & b7 as compared to those with binders b1, b3 and the commercial binder especially in case of using these binders for printed polyester fabric. The rub fastness ranges from good to very good in case of using the binders b2, b4, b5, b6, b7 and commercial binder and ranges from moderate to good in case of using binders b1 & b3. The wash and perspiration fastness range from very good to excellent for all binders. The amount of energy that can be transformed depends on the absolute temperature of body and radiation properties of the surface.

The roughness properties are observed for screen printed polyester fabrics, using printing pastes containing 4% Bercolin Red B3E, 1% of the synthesized polyurethane acrylate binders (b1-b7), as well as the commercial and microwave cured for 5min at 500 watt. The data show that the roughness for all these printed fabrics depends on the type of binder used. Binders 2 and 5 give higher roughness results compared to commercial binder used (commercial binder = 14.8, b1= 11.7, b2= 15.1, b3= 10.5, b4= 13.9, b5 = 16.43, b6 = 12.00 and b7= 11.76).

4 Conclusion

4.1 The color strength of printed polyester fabric depends mainly on binder type and more or less on binders concentration as well as the fixation temperature. The more polymerization can be achieved by rising the fixation temperature.

4.2 \( K/S \) values at lower fixation temperature on using the prepared binders in the printing paste are better than the \( K/S \) values of fabric printed with paste including commercial binder at the same condition.

4.3 The binders b1, b3 & b6 seem to have the highest color strength values, and the fixation temperature of around 160°C could be recommended for synthesized binders at 1% binder concentration and 4 min time of fixation.

4.4 Elevated \( K/S \) values are obtained with printing pastes containing binders b4 & b6 and the moderated
\( K/S \) values are obtained with printed polyester fabric in cases of binders b1, b3 & b7. The higher binder concentration is not recommended. The concentration of 1% polyurethane acrylate binder in the polyester pigment printing paste and UV curing of the printed samples for 3 min could be considered as optimum conditions in this case.

4.5 Elevated \( K/S \) values are obtained with printing pastes containing binders b1, b6 & b7. Curing time does not affect the color strength of the prints, irrespective of binder type or their concentration.

4.6 The wash and perspiration fastness are in the range of very good to excellent for all samples printed with paste including the prepared binders as well as the commercial binder, irrespective of the type of fabric.

4.7 The rub fastness results are found to be acceptable for thermally cured polyester printed samples. The rub fastness ranging from good to very good is obtained in case of using the binders b1, b2, b4, b5, b6 and commercial binder. The values ranging from moderate to good are obtained in case of using binders b3 & b7.

4.8 The rub fastness for UV cured polyester are found to be from good to very good in case of using the binders b1, b3, b4, b5 and commercial binder and moderate to good in case of using binders b2, b6 & b7.

4.9 The rub fastness of printed samples using microwave curing technique ranges from good to very good in case of binders b2, b4, b5, b6, b7 and commercial binder and from moderate to good in case of using binders b1 & b3.

References