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Synthesis of polyurethane acrylate oligomers as aqueous UV-curable binder for inks of ink jet in textile printing and pigment dyeing

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Abstract

Polyurethane acrylate oligomers were prepared from isophorone diisocyanate, mixture of polyethylene glycol 1000 and 2000 and hydroxy ethyl acrylate using dibutyl tin dilaurate as a catalyst. The rheological properties and its utilization as a UV-curable binder for inks of ink jet printing and pigment dyeing of cotton, viscose, wool, polyester and nylon 66 fabrics using pigment dyes were thoroughly investigated. It was found that the prepared binder is characterized by low viscosity (0.0042 Pa S = 4.2 cP) at a rate of shear of 10.0007 S^{-1}. Furthermore, the results obtained indicate that the aqueous UV-curable binder of polyurethane acrylate oligomer based on the mixture of PEG_{1000} and PEG_{2000} can be used safely for inks of ink jet printing and also in pigment dyeing to give coloured goods characterized by soft handling and from good to excellent color fastness properties. Infra-red spectra of the mixture of PEG_{1000} and PEG_{2000} before and after the preparation of polyurethane acrylate oligomer indicate some physicochemical changes in the structure.

Keywords: Synthesis; Polyurethane acrylate; Oligomers; Aqueous UV-curable; Binder; Inks; Ink jet; Textile printing pigment dyeing

1. Introduction

Ink jet printing and UV-curing technologies have developed in parallel. Manufacturers have integrated ink jet print heads, printing mechanisms, UV-curable inks and UV-curing systems to address a number of industrial printing needs [1]. The use of UV-curable ink with analog printing methods, including flexography, gravure, offset and screen process, is growing at a rate that exceeds the growth rates for the use of these processes. For example, the total flexographic ink market for labels is projected to grow at 3% per annum, while UV-curing ink is growing at 17% [2]. The printing industry adopted UV-curing inks and coatings because they emit little to no volatile organic compound (VOC) solvents, do not dry during print process before curing, but will dry almost instantly when cured, and the curing equipment occupies much less space than the conventional thermal drying convegors. The US Environmental Protection Agency views UV-curable inks as a green technology that it deems preferable to conventional solvent-based ink systems [1].

Currently, pigment printing is perhaps the most commonly and extensively used technique for printing textile, due to its easy application to a variety of fabrics and relatively clean and environmentally friendly aspects [3,4]. On a global basis, about 50% of printed textiles are processed by pigment printing. In the United States, the share reaches nearly 88%, in England 50%, and in China 60–80% [5]. However, pigment printing has a few problems such as relatively high temperature cure, stiff hand, and poor crock fastness of printed goods. Formaldehyde emissions and clogging on the screens during the actual printing process must also be taken into account [6–8]. These disadvantages are related to the binders used. Thus, to improve the quality of the pigment printed goods, the overall properties of the binder need to be improved.

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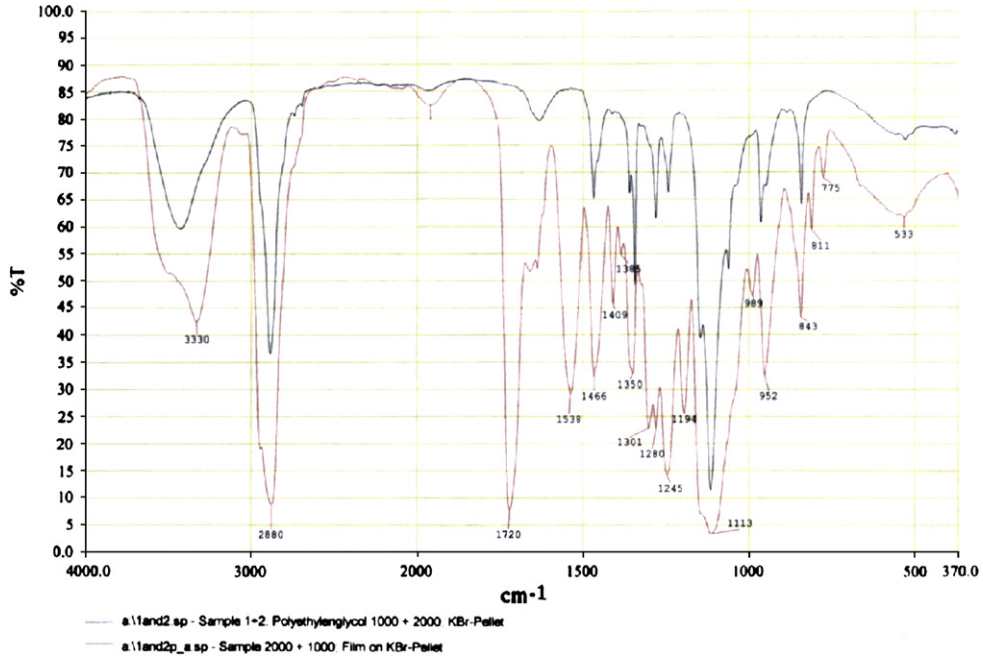


Fig. 1. IR spectra of mixed polyethylene glycol 1000 + 2000 before and after the preparation of polyurethane acrylate based on $PEG_{1000+2000}$.

The aim of the present work is to prepare aqueous UV-curable binder of polyurethane acrylate oligomers based on the mixture of PEG_{1000} and PEG_{2000}. These compounds having low viscosity measurement can be used either in inks of ink jet printing or for pigment dyeing for all types of fabrics using pigment dyes.

2. Experimental

2.1. Materials

- Polyethylene glycol (PEG, Mn 1000 and 2000) was supplied by Merck, Germany. PEG_{1000} was dried and degassed at 90 °C/1−2 mm Hg until no bubbling was observed.
- Isophorone diisocyanate (IPDI) supplied by Lyondell Chemical Co., Germany, dibutyl tin dilaurate (DBTDL) as a catalyst supplied by Fluka Chemical Co., Switzerland and hydroxy ethyl acrylate supplied by Degussa, Germany were used without further purification.
- Mill scoured, bleached and mercerized plain weave cotton fabric (135 g/m^2), wool fabric [100% wool] of 145 g/m^2, polyamide fabric [100% nylon 66] of 110 g/m^2, polyester fabric [100% PES, satin] of 85 g/m^2 and viscose fabric [100% viscose] of 140 g/m^2 were supplied by private sector co.
- Pigment dispersions for ink jet printing have narrow particle distribution and mean particle size around 165 nm, which is pigment Blue 153-16 (10% PiG) supplied by Minerva miner print, Italy.
- Commercial binder, Ebecryl 2002 was supplied by surface specialties (UCb Chemicals), Belgium.
- Photoinitiator, Esacure DP 250 was supplied by Iamberti SPa, Italy.

2.2. Methods

2.2.1. Synthesis of polyurethane acrylate oligomers

The reaction of mixture of PEG_{1000} and PEG_{2000} with IPDI was conducted according to a procedure described elsewhere [9,10] which was modified and carried out as follows: mixture of PEG_{1000} and PEG_{2000} was added as a 70% acetone mixture into a three-necked flask equipped with stirrer, thermometer, and reflux condenser under nitrogen atmosphere. IPDI containing 0.05% (w/w) DBTDL was slowly dropped into the reactor at 40 °C for over an hour and the reaction mixture was stirred

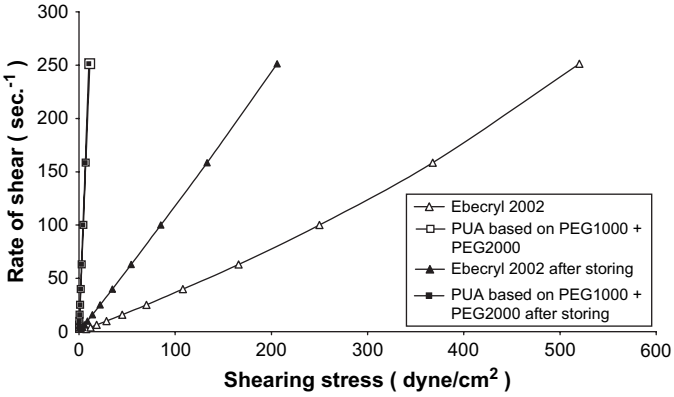


Fig. 2. Rheological properties of aqueous UV-curable binder of polyurethane acrylate based on the mixture of $PEG_{1000+2000}$ and/or Ebecryl 2002 (10%) before and after storing for 10 days.

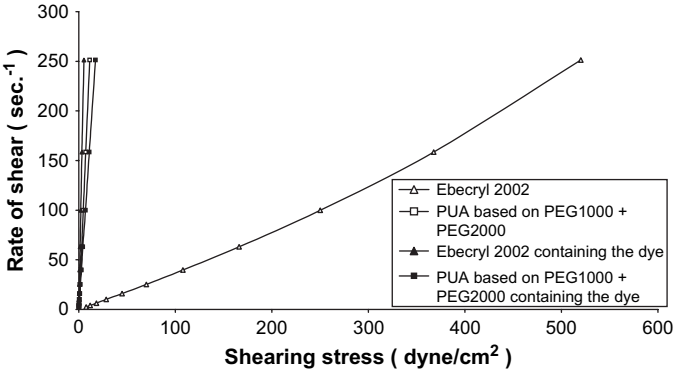


Fig. 3. Rheological properties of aqueous UV-curable binder of polyurethane acrylate based on the mixture of $PEG_{1000+2000}$ and/or Ebecryl 2002 (10%) before and after preparing ink using 20% Blue pigment 153-16 (10% piG).

for an additional 1 h at 50 °C to ensure an acceptable reaction rate without gelation. A calculated amount of hydroxy ethyl acrylate was gradually added to the reaction mixture for over an hour at 60 °C and the reaction mixture was stirred for another 2 h continuously at 60 °C to cap all of the terminal NCO group. The resulting product was a clear solution of polyurethane acrylate oligomers. Deionized water was added into the kettle to form an aqueous solution of polyurethane acrylate binder with 40% (w/w) solids content. The reaction yield was evaluated.

2.2.2. Ink preparation

Aqueous pigmented inks are composed of Blue 153-16 (10% PiG), Esacure DP 250, and Ebecryl 2002 as a binder and/or the prepared binder of polyurethane acrylate based on the mixture of PEG_{1000} and PEG_{2000} and deionized water.

2.2.3. Coloration of the textile and dye fixation

The printing of textile using Drop-on Demand ink jet printing engine is the piezo head (Mimaki JV2-130, Japan) or dyeing using a padding machine (Foulard), Switzerland. The dried textile fabric was padded through the prepared ink at 100% wet pickup. The padded fabrics were only air dried (or oven dried at 80 °C for 30 s) and then the fabrics were subjected to UV light source (Fusion UV-curing systems model K52312, USA) for 20 s (5 passes at 4 s per pass) to fix the color, through polymerization process.

2.3. Testing and measurements

2.3.1. Rheological properties

The rheological properties and apparent viscosity of the prepared binder of aqueous polyurethane acrylate solution of 10% (w/w) were measured using fluids spectrometer RFS II (Rheometrics Co 1483), Germany, at 25 °C and at different shear rates.

2.3.2. Infra-red analysis

The infra-red of the mixture of polyethylene glycol (1000 and 2000) before and after the preparation of the polyurethane acrylate based on polyethylene glycol (1000 and 2000) was measured using Infra-red spectrometer, Perkin Elmer, system 2000 FT-IR (Fourier transform IR spectrometer).

2.3.3. Surface tension measurement

The surface tension of the inks was measured with a calibrated Kruss K12 surface tensiometer (Kruss, Hamburg, Germany). It determines the force required to detach a platinum ring from the surface of the ink. The measurement procedure was repeated six times to obtain an average value of the force. Before each sample measurement the ring was thoroughly rinsed in distilled water and flamed by a Bunsen burner to remove any residue. This preparation is needed because the condition of the ring is crucial for the measurement accuracy [11].

2.3.4. Conductivity measurement

The conductivity was measured by a conductivity meter LF318 standard conductivity cell Tetra cons, Germany.

2.3.5. Color strength

The relative color strength of the prints expressed as *K*/*S* value [12] of the coloured samples was determined by reflection measurements using data color international model SF 500, USA.

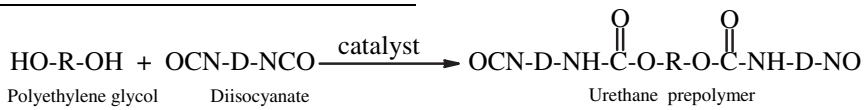
2.3.6. Fastness properties

Fastness to washing [13], rubbing [14] and perspiration [15] was assessed according to the standard methods.

3. Results and discussion

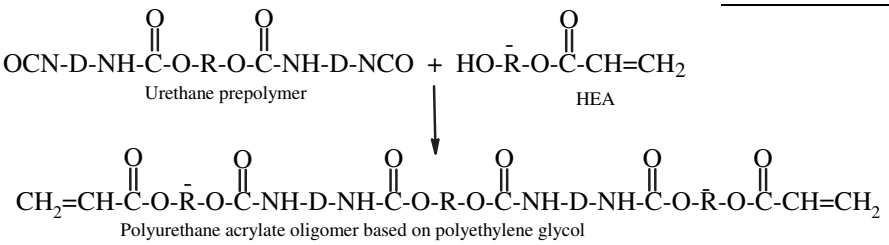
3.1. Synthesis of polyurethane acrylate oligomer

Most acrylated oligomers are based on polyether, polyester, and epoxy resins. This is because the functionality of these condensation resins can be precisely controlled to 2 or 3 to prevent gelling and to keep viscosity at low, diisocyanate could react with polyethylene glycol to form isocyanato-terminated polyurethane prepolymer. The reaction can be represented as follows:



where R = $-CH_2-CH_2-(O-CH_2-CH_2)_n-O-CH_2-CH_2-$ and D = Isophorone

After that the urethane prepolymer reacted with hydroxy ethyl acrylate to give polyurethane acrylate oligomer based on polyethylene glycol as follows:



Where $\bar{R}$ = -CH_2-CH_2-

The formation of the polyurethane acrylate oligomer was evidenced by the emergence of the strong absorption at 1245 cm^{-1} (C–O), 1466 cm^{-1} (C–N–C), 1538 cm^{-1} (N–CO), 1620 cm^{-1} (N–H), 1637 cm^{-1} (C=C), 1720 cm^{-1} (C=O) and the sharpening of the absorption band at 3330 cm^{-1} as shown in Fig. 1, which is the infra-red spectra of the mixture of PEG_{1000} with PEG_{2000} (1:1) before and after the preparation of the polyurethane acrylate based on the mixed PEG. It is also clear from the infra-red spectra that there is no absorption band at approximately 2274 cm^{-1} [16] which corresponds to NCO group, and this indicates that the entire amount of isophorone diisocyanate enters into the reaction and the end product is free from isocyanate. All this confirm the occurrence of the addition reaction to obtain the aqueous UV-curable binder of polyurethane acrylate oligomer based on the mixture of PEG_{1000} and PEG_{2000}.

3.2. Rheological properties

The rheological properties and viscosity of polyurethane acrylate based on the mixture of PEG_{1000} and PEG_{2000} and/or Ebecryl 2002 (10%) before and after storing for 10 days were measured using Rheometrics CO 1483. The rheological properties were measured at 25 °C. The rheograms are given in Fig. 2. It is clear from these rheograms that all samples are characterized by non-Newtonian pseudoplastic behavior where, the up and down flow curves are coincident. It is also clear from the same figure that the location of the rheogram and its slope seems to be not only dependent on the type of binder used but also on the time of storage. When commercial binder used, which is Ebecryl 2002, the rheogram curve shifted far from the axis of the rate of shear indicating an increase in the apparent viscosity, but storage has a significant effect on its apparent viscosity as the rheogram curve after storing for 10 days was shifted nearest to the axis of the rate of shear, indicating a decrease in its apparent viscosity. While the rheogram curves of prepared binder which is polyurethane acrylate oligomer before and after storing for 10 days are nearly the same and are coincident indicating that there is no change in the viscosity after storage, and the rheogram curves are nearest to axis of the rate of shear, indicating a decrease in the apparent viscosity.

The apparent viscosity decreased with increasing rate of shear. At constant rate of shear, the apparent viscosity of Ebecryl 2002 is higher than that of PUA based on $PEG_{1000+2000}$ and it decreased by storage e.g. at a rate of shear of 10.0007 s^{-1}, the viscosity of freshly prepared Ebecryl 2002 is 285 cP but the viscosity of PUA based on $PEG_{1000+2000}$ is 4.85 cP, after storage for 10 days the viscosity of Ebecryl 2002 is 88.5 cP and the viscosity of PUA based on $PEG_{1000+2000}$ is 4.32 cP.

Fig. 3 shows the rheological behavior of PUA based on $PEG_{1000+2000}$ and Ebecryl 2002 before and after the preparation of ink using 20% Blue pigment 153-16 (10% PiG).

It is seen that the rheogram curve of Ebecryl 2002 without dye was shifted far from the axis of the rate of shear indicating an increase in the apparent viscosity but after using prepared ink using the Blue pigment 153-16, the rheogram curve was shifted nearest to the axis of the rate of shear indicating a decrease in the apparent viscosity but the inverse happened in case of PUA based on $PEG_{1000+2000}$ e.g. at a rate of shear of 10.0007 s^{-1} the viscosity of Ebecryl 2002 without dye is 285 cP and when we added the dye it decreased to 2.6 cP but in case of PUA based on $PEG_{1000+2000}$ it increased from 4.85 to 6.99 cP and this may be due to the dispersant medium of the Blue pigment containing some groups which result in cross-linking or hydrogen bonding with PUA oligomer based on

Table 1
Apparent viscosity, surface tension, conductivity and pH measurements of the prepared water-based ink using UV-curable binder of polyurethane acrylate based on the mixture of PEG_{1000} and PEG_{2000} and/or Ebecryl 2002 using 20% Blue pigment 153-16 (10% piG)

Binder used	Binder concentration (%)	Viscosity at rate 10.0007 S^{-1} (Pa S)	Surface tension (mN/m)	Conductivity (μS/cm)	pH
Ebecryl 2002	5	0.00133	34.163	715	7.95
	10	0.00257	35.675	813	6.83
	20	0.00905	38.404	970	6
PUA based on $PEG_{1000+2000}$	5	0.00312	33.527	837	7.89
	10	0.00699	35.401	749	7.75
	20	0.0373	36.274	533	7.62

1 Pa S = 1000 cP.

$PEG_{1000+2000}$ which leads to an increase in the molecular weight and this leads to an increase in the viscosity but the inverse happened in case of Ebecryl 2002, where as this groups make dilution in the oligomer chains and this is due to the different in the first component of polyol of the two binder used.

3.3. Ink property measurements prepared using aqueous UV-curable binder

The evaluation of the ink stability requires a constant monitoring of various ink properties. The quantitative ink data are obtained through the following measurements such as, viscosity, surface tension, conductivity and pH measurements. The viscosities of water-based inks are relatively low, usually less than 10 cP. Table 1 shows the viscosity, surface tension, conductivity and pH measurements of prepared water-based ink using prepared UV-curable binder of polyurethane acrylate based on the mixture of $PEG_{1000+2000}$ and/or Ebecryl 2002 using Blue pigment 153-16. It is clear from the data in Table 1 that the viscosity of ink on using Ebecryl 2002 by 10% is lower than the viscosity of ink on using PUA based on $PEG_{1000+2000}$ by 5% which is equal 2.57 cP compared with 3.12 cP, but in the case of used ink containing 10% of PUA based on $PEG_{1000+2000}$ the viscosity is equal 6.99 cP. The surface tension increases with increase in the concentration of binder, but the pH decrease and the conductivity in case of used Ebecryl 2002 as a binder in the ink preparation its increase by increase the concentration of Ebecryl 2002 but the inverse is true in case of used PUA based on $PEG_{1000+2000}$ and this may be due to increase the concentration lead to high increase in the viscosity on compared with Ebecryl 2002 which leads to decrease in the conductivity.

3.4. Using the prepared ink in ink jet printing of textile fabric

Table 2 shows the color strength and fastness properties of ink jet printed cotton, viscose, wool, nylon 66 and polyester fabrics using prepared PUA based on $PEG_{1000+2000}$ by concentration 5% and Ebecryl 2002 by concentration 10% as UV-curable binders using Blue pigment 153-16. It is clear from the data in Table 2 that in spite of the lower concentration of PUA based on $PEG_{1000+2000}$ (5%) used in prepared ink for ink jet printing but give higher color strength in case of viscose, nylon 66 and polyester fabric and slightly lower values in case of cotton compared with the Ebecryl 2002 which is used by (10%) and this may be due to the difference in the first component of the two binders, used may be in case of used mixture of $PEG_{1000+2000}$ the average of hydroxyl values is higher than the first component of polyol which is used for prepared Ebecryl 2002 and this is lead to not only increase in the urethane groups in the prepared binder but also increase in the number of unsaturation site of vinyl group which is responsible for fixed of the dispersed pigment using UV light through the polymerization process. All the printed goods were characterized by soft handle. Also it is clear from the data in Table 2 that the color fastness to rubbing in case of cotton, viscose and nylon 66 ranged from good to very good but in case of polyester ranged from moderate to good and in case of wool from poor to moderate. Furthermore the color fastness to washing in case of cotton, viscose ranged from good to very good but in case of wool, nylon 66 and polyester ranged from poor to moderate. The color fastness to perspiration in case of cotton and viscose ranged from very good to excellent and in the other fabrics it is very good. This was true irrespective of the nature of the binder used for prepared ink for ink jet printing.

3.5. Using the prepared ink in dyeing of textile fabric through padding process

3.5.1. Effect of the type and concentration of UV-curable binder

The effect of the type and concentration of binder used on the color strength of the coloured cotton, viscose, wool, nylon 66 and polyester fabric upon using polyurethane acrylate

Table 2
Colour strength and overall fastness properties of ink jet printed fabrics using prepared polyurethane acrylate based on the mixture of PEG_{1000} and PEG_{2000} and/or Ebecryl 2002 as UV-curable binders for ink preparation using 20% Blue pigment 153-16 (10% piG)

Binder used	Type of fabric	Colour strength	Rubbing fastness		Washing fastness		Perspiration fastness			
							Acidic		Alkaline	
			Dry	Wet	Staining	Alteration	Staining	Alteration	Staining	Alteration
Ebecryl 2002 (10%)	Cotton	3.49	3–4	3	3	4	4	5	5	5
PUA based on $PEG_{1000+2000}$ (5%)		3.33	3	3–4	3	4	4	5	5	5
Ebecryl 2002 (10%)	Viscose	3.66	3	3	2–3	3	4	5	4	4
PUA based on $PEG_{1000+2000}$ (5%)		4.01	3	3	2–3	3	5	5	4	5
Ebecryl 2002 (10%)	Wool	2.48	1–2	1–2	3	2	4	4	4	4
PUA based on $PEG_{1000+2000}$ (5%)		1.97	1–2	1–2	2	1	4	4	5	4
Ebecryl 2002 (10%)	Nylon 66	2.61	3–4	3	2–3	2	3	4	2	4
PUA based on $PEG_{1000+2000}$ (5%)		3.01	3–4	2–3	2	2	4	4	4	4
Ebecryl 2002 (10%)	Polyester	2.54	2–3	2–3	2	1	4	4	3–4	4
PUA based on $PEG_{1000+2000}$ (5%)		2.63	2–3	2	2	1	4	4	4	4

The washing fastness in case of cotton and viscose is at 60 °C, but in case of wool, nylon 66, and polyester it is at 40 °C.
All samples showed soft handling.

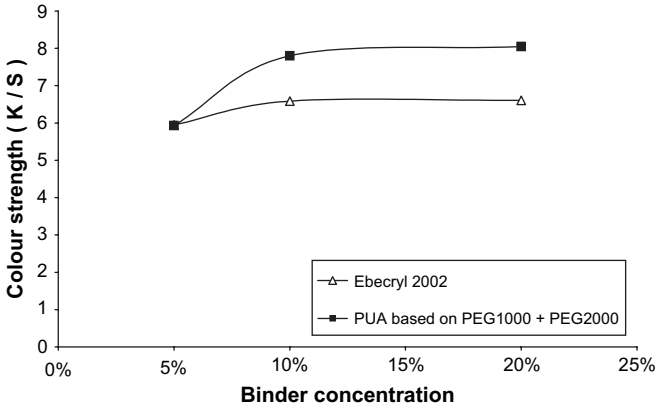


Fig. 4. Effect of the concentration of the aqueous UV-curable binder used in the prepared ink on the *K*/*S* of the coloured cotton fabric using 20% Blue pigment 153-16 (10% piG).

oligomer based on the mixture of PEG_{1000} and PEG_{2000} and/or Ebecryl 2002 as UV-curable binders in the prepared ink using 20% Blue pigment 153-16 (10% PiG) is represented by Figs. 4–8. It is clear from Figs. 4–8 that in case of using Ebecryl 2002, as the concentration increases a slower rate of increase in the color strength or may be fixed, this was true irrespective of the type of coloured fabric. But in case of using polyurethane acrylate based on the mixture of PEG_{1000} and PEG_{2000}, as the concentration increases the color strength of the coloured fabrics increases. Furthermore, on using polyurethane acrylate based on the mixture of PEG_{1000} and PEG_{2000} as a UV-curable binder in ink preparation, the color strength results are higher than the color strength results on using Ebecryl 2002. For example the *K*/*S* values were 8.05, 10.17, 9.05, 8.31 and 7.95 for cotton, viscose, wool, nylon 66, and polyester, respectively, on using 20% of polyurethane acrylate based on the mixture of PEG_{1000} and PEG_{2000} as a UV-curable binder in ink preparation, while it was 6.61, 7.42, 5.86, 7.4 and 6.55 for cotton, viscose, wool, nylon 66 and polyester, respectively, on using 20% of Ebecryl 2002, this may be due to the difference in the structure and the amount of unsaturation groups of the two binders.

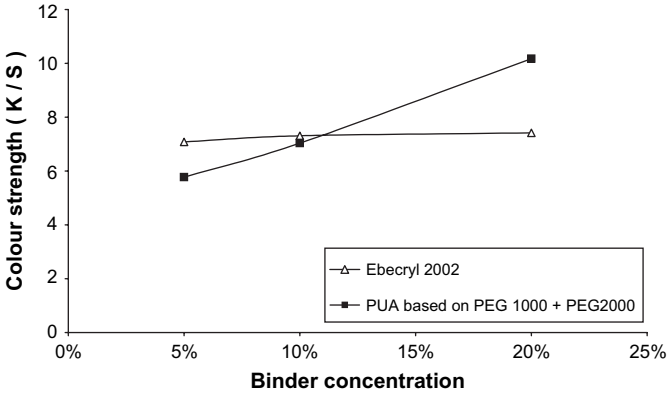


Fig. 5. Effect of the concentration of the aqueous UV-curable binder used in the prepared ink on the *K*/*S* of the coloured viscose fabric using 20% Blue pigment 153-16 (10% piG).

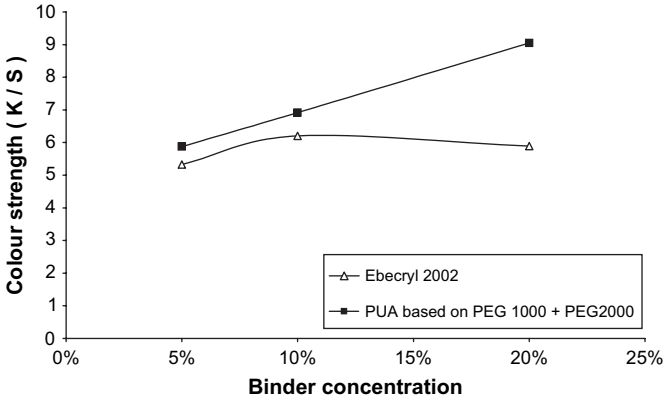


Fig. 6. Effect of the concentration of the aqueous UV-curable binder used in the prepared ink on the *K*/*S* of the coloured wool fabric using 20% Blue pigment 153-16 (10% piG).

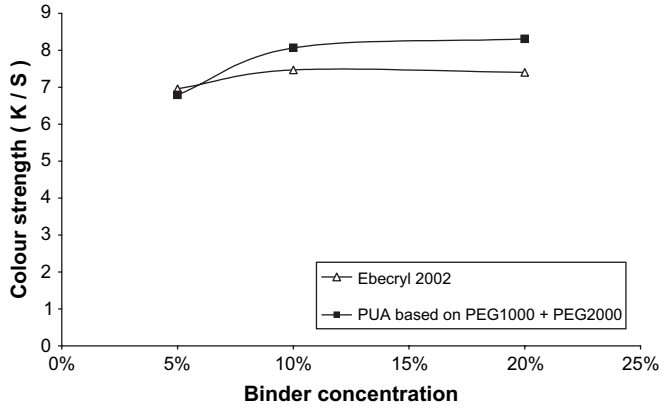


Fig. 7. Effect of the concentration of the aqueous UV-curable binder used in the prepared ink on the *K*/*S* of the coloured nylon 66 fabric using 20% Blue pigment 153-16 (10% piG).

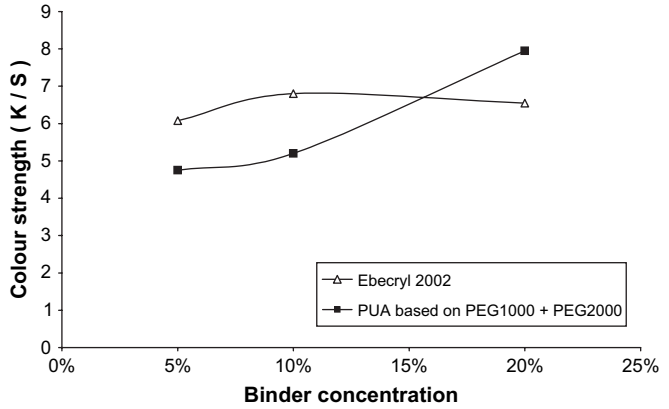


Fig. 8. Effect of the concentration of the aqueous UV-curable binder used in the prepared ink on the *K*/*S* of the coloured polyester fabric using 20% Blue pigment 153-16 (10% piG).

3.5.2. Fastness properties

Tables 3–7 show the color strength and fastness properties of coloured cotton, viscose, wool, nylon 66 and polyester fabrics using prepared polyurethane acrylate based on the mixture of PEG_{1000} and PEG_{2000} and/or Ebecryl 2002 as aqueous

Table 3
Colour strength and overall fastness properties of coloured cotton fabrics using prepared polyurethane acrylate based on the mixture of PEG_{1000} and PEG_{2000} and/or Ebecryl 2002 as UV-curable binders for ink preparation using 20% Blue pigment 153-16 (10% piG)

Binder used	Binder concentration (%)	Colour strength	Rubbing fastness		Washing fastness			Perspiration fastness					
								Acidic			Alkaline		
			Dry	Wet	Staining on		Alt.	Staining on		Alt.	Staining on		Alt.
					Cotton	Wool		Cotton	Wool		Cotton	Wool	
Ebecryl 2002	5	5.95	3	2–3	3	3	5	4	2–3	5	4	3	5
	10	6.59	3	3	3	4	5	4	4	5	4	4	5
	20	6.61	3	3–4	3–4	4–5	5	5	4	5	5	4	5
PUA based	5	5.93	3	2–3	3	4	5	4	3	5	4	3	5
on the mixture	10	7.8	3	3	3	4	5	4–5	4	5	4–5	4	5
of PEG_{1000} and PEG_{2000}	20	8.05	3–4	3	3–4	4–5	5	4–5	4	5	4–5	4	5

The washing fastness is at 60 °C; Alt. = alteration.
All samples showed soft handling.

Table 4
Colour strength and overall fastness properties of coloured viscose fabrics using prepared polyurethane acrylate based on the mixture of PEG_{1000} and PEG_{2000} and/or Ebecryl 2002 as UV-curable binders for ink preparation using 20% Blue pigment 153-16 (10% piG)

Binder used	Binder concentration (%)	Colour strength	Rubbing fastness		Washing fastness			Perspiration fastness					
								Acidic			Alkaline		
			Dry	Wet	Staining on		Alt.	Staining on		Alt.	Staining on		Alt.
					Cotton	Wool		Cotton	Wool		Cotton	Wool	
Ebecryl 2002	5	7.08	3	2–3	2	3	4	4	3	5	4	3	5
	10	7.31	3	2–3	3	3	4	4	3–4	5	4	3–4	5
	20	7.42	3–4	3	3	3–4	4	4	4	5	4	4	5
PUA based	5	5.77	3	2–3	2	2	3	4	3	5	4	4	5
on the mixture	10	7.04	3–4	3	2	3	3	4	4	5	4	4	5
of PEG_{1000} and PEG_{2000}	20	10.17	4	3	2–3	4	3	4	4	5	4	4	5

The washing fastness is at 60 °C; Alt. = alteration.
All samples showed soft handling.

Table 5
Colour strength and overall fastness properties of coloured wool fabrics using prepared polyurethane acrylate based on the mixture of PEG_{1000} and PEG_{2000} and/or Ebecryl 2002 as UV-curable binders for ink preparation using 20% Blue pigment 153-16 (10% piG)

Binder used	Binder concentration (%)	Colour strength	Rubbing fastness		Washing fastness			Perspiration fastness					
								Acidic			Alkaline		
			Dry	Wet	Staining on		Alt.	Staining on		Alt.	Staining on		Alt.
					Cotton	Wool		Cotton	Wool		Cotton	Wool	
Ebecryl 2002	5	5.33	2	2–3	3	3	1	5	3	4	4	3	4
	10	6.2	2	2–3	3–4	3–4	1	5	4	4	5	4	4
	20	5.89	2	3	4	4	1	5	4	5	5	4	5
PUA based	5	5.88	3	2–3	2	3	1	4	3	4	4	3	4
on the mixture	10	6.92	3	2–3	2–3	3	2	4	4	5	4–5	4	5
of PEG_{1000} and PEG_{2000}	20	9.05	3	2–3	2–3	4	2–3	4	4	5	4–5	4	5

The washing fastness is at 40 °C; Alt. = alteration.
All samples showed soft handling.

Table 6
Colour strength and overall fastness properties of coloured nylon 66 fabrics using prepared polyurethane acrylate based on the mixture of PEG_{1000} and PEG_{2000} and/or Ebecryl 2002 as UV-curable binders for ink preparation using 20% Blue pigment 153-16 (10% piG)

Binder used	Binder concentration (%)	Colour strength	Rubbing fastness		Washing fastness			Perspiration fastness					
								Acidic			Alkaline		
			Dry	Wet	Staining on		Alt.	Staining on		Alt.	Staining on		Alt.
					Cotton	Wool		Nylon 66	Wool		Nylon 66	Wool	
Ebecryl 2002	5	6.96	3	1–2	2–3	3	2	2–3	2–3	4	3	3	4
	10	7.47	3–4	2–3	2–3	3	2	4	2–3	5	4	3	5
	20	7.4	3–4	2–3	3	4	2	4	2	5	4	4	5
PUA based	5	6.79	2–3	2	1–2	3	1	2–3	2–3	4	3	3	4
on the mixture	10	8.07	3–4	2–3	1–2	3	1–2	3	3	4	4	4	4
of PEG_{1000} and PEG_{2000}	20	8.31	3–4	3	2	4	2	4	4–5	4	4	4–5	5

The washing fastness is at 40 °C; Alt. = alteration.
All samples showed soft handling.

UV-curable binders in the prepared ink using (20%) Blue pigment 153-16 (10% PiG). All coloured goods were characterized by soft handle, on the other hand, the color strength depended on both the nature of the binder used and on its concentration. The highest color strength was obtained using higher concentration of the binder, also it is clear from the data in Tables 3–7 that the rubbing, washing and perspiration fastness improve by increase in the concentration of the binder used. This was true irrespective of the nature of the binder used and/or the type of coloured fabrics. This may be due to the increase in the concentration of the binder that leads to an increase in the amount of the unsaturation site of vinyl group which is responsible for the fixation of the dispersed pigment using UV light through the polymerization process.

Also it is clear from the data in Tables 3–7 that the fastness properties' values upon using prepared polyurethane acrylate based on the mixture of PEG_{1000} and PEG_{2000} and/or commercial Ebecryl 2002 as UV-curable binders are comparable. The washing, rubbing and perspiration fastness results range between good to very good for rubbing and washing fastness and range between very good to excellent for perspiration fastness. The defect was found in case of wet rubbing fastness and change in color after washing for coloured wool, nylon 66 and polyester fabric using 5 and 10% concentration of the binder for ink preparation and this may be due to either the type of dye used or these types of fabrics need some chemical treatment to improve this defect before coloring by using this type of binders. Also from Tables 5–7 we noticed that the increase in the concentration of binder used improved this defect.

4. Conclusion

- Aqueous UV-curable inks were formulated with zero volatile organic compounds and less than 10 cP viscosity using prepared polyurethane acrylate oligomer based on the mixture of PEG_{1000} and PEG_{2000} as a binder for ink preparation.
- The highest color strength is obtained by increasing the concentration of binder used and also the all fastness properties are improved.
- The polyurethane acrylate based on the mixture of PEG_{1000} and PEG_{2000} can be used safely as a UV-curable binder for ink preparation to be used either in ink jet printing or for dyeing by padding process of all type of fabric using pigment dyes.

Table 7
Colour strength and overall fastness properties of coloured polyester fabrics using prepared polyurethane acrylate based on the mixture of PEG_{1000} and PEG_{2000} and/or Ebecryl 2002 as UV-curable binders for ink preparation using 20% Blue pigment 153-16 (10% piG)

Binder used	Binder concentration (%)	Colour strength	Rubbing fastness		Washing fastness			Perspiration fastness					
								Acidic			Alkaline		
			Dry	Wet	Staining on		Alt.	Staining on		Alt.	Staining on		Alt.
					Cotton	Wool		Polyester	Wool		Polyester	Wool	
Ebecryl 2002	5	6.08	3	1–2	1–2	2–3	1	4	4	4	4	3	4
	10	6.8	3–4	2	2	3	1–2	4	3–4	4	4	4	4
	20	6.55	3–4	2	3	3–4	2	4	3–4	4	4	4	4
PUA based	5	4.75	3	2	1–2	3	1	3–4	4	4	4	3	4
on the mixture	10	5.2	3–4	2	1–2	3	1–2	4	3–4	4	4	4	4
of PEG_{1000} and PEG_{2000}	20	7.95	4–5	2–3	2–3	4	2	4	3–4	4	4	4	4

The washing fastness is at 40 °C; Alt. = alteration. All samples showed soft handling.

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