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A Critique on Synthesis and Application of Binders in Textiles Pigment Printing

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Abstract

Objectives: Textile auxiliaries are commonly used in many textile wet processes including dyeing and printing. Herein, we criticize the different methods used in the synthesis and applications of binders in pigment printing of textile fabrics.
Methods: Binders are used to hold the color onto the textile surface when applying pigments for textile printing. Most of the binders used in textile printing are based on the addition of polymerization systems. When a binder is applied with pigment to textile, it forms a three-dimensional network, this is due to the binders being considered as a film-forming from long-chain macromolecules.
Findings: The choice of binders depends on the final fastness properties as well as the cost requirements of the process. Many different binders were developed for other purposes, resulting finally in the use of emulsions. This led to an increase in the use of pigments in textile printing and the binder has become one of the basic matters utilized in the printing paste. Biopolymers would be appropriate elements in the production of eco0frienddly binders suitable for benign printing of textile substrates.
Novelty: This review presents some negotiable points regarding the binder's functions together with its chemistry, synthesis as well as its mode of action, and its effect on the extent of fixation of the pigment on the printed textile surface.

Key words: Binder, synthesis, chemistry, technology, textile printing, printing paste

1. Introduction

Textile auxiliaries are usually added to enhance the performance of many wet processes of textile substrates [1,2]. Among others, the commonly used auxiliaries in the textile field include wetting agents, binders, thickeners, softeners, sizing agents, flame retardants, anti-microbial agents, anti-setting agents, and shrink-proofing agents [3,4]. Dyeing and printing are usually applied to textile products to improve their appearance, and in few cases performance, attributes [5,6]. Practically, there are differences between these two processes; textile dyeing is a process that is used to apply color to the whole fabric surface, while printing is partial dyeing to form a certain model. Dyeing could be achieved in an aqueous solution [7], while printing could be achieved with pigment by using a printing paste [8]. Textile pigment printing is considered the oldest and easiest method for simplicity of printing method application [9]. Pigment printing has many obvious advantages such as the ability to adapt or be adapted to many different functions, ease of application, applicable to almost every fabric type and/or blended fabrics, and the capability to avoid any dye off after fixation processes, there for most of the printed fabrics depended on pigment printing [10,11].

In the past, the printers of fabric were used colored metal oxides, naturally occurring organic pigments, and any other colored materials to apply color into fabric [12]. Pigment printing differs from other printing methods in that, the insoluble pigments, which have no affinity for the fabric and the pigment is fixed to the fabric by a binding agent named binder which adheres to the fabric and forms a continuous film on it enclosing the pigment molecules [13].

Textile binder materials are necessary to form a film to trap pigment molecules and must be resistant to various external factors that may tend to expel the

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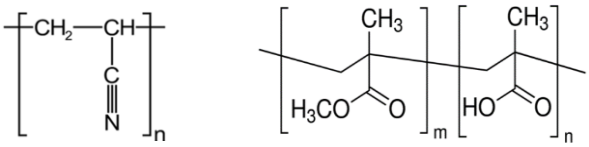
pigments from the coloring textile, as washing or rubbing. When the binder is selected it must be characterized by several functions to get low cost and colorful fabrics that perform the final purpose of use and their colors are stable [14].

Herein, the innovative technologies adopted to enhance synthesis of binder and its application in textile printing, were intensively discussed. The adopted green technologies in textile printing were also reviewed.

2. Section 1: Binders History

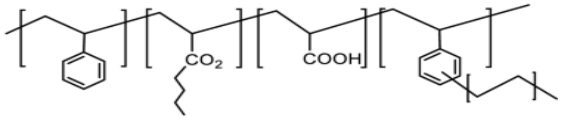
Textile auxiliaries are pronounced during dyeing and finishing of textile fibres and fabrics [15]. The use of binders is very important in producing pigment-colored fabrics. In many cases, the fastness properties of the printed fabrics are usually adequate and/or appropriate for the majority of end-user specifications [16–18]. According to the nature of the process, the hand feeling of the fabric being colored is very important and it will be slightly harsher than the un-colored one. With the proper binder selection, and the application methods as well as variables, it is possible to produce an acceptable compromise in this consideration. While the hand feeling is essential, it is not the only criteria used in binder selecting as there are other properties such as durability, measured through color retention, are also important. Several binders have no ability to form bonds between pigment and fabrics. Consequently, the binder that meets performance requirements on many levels is almost required [19]. Examples of some common polymers used as binders in textile pigment printing are shown in Figure 1.

In the mid 1930's, the specialists had adopted fabric printing systems based on ethyl cellulose and nitrocellulose, but the printed fabrics were very stiff and the rubbing fastness was poor. Researcher utilized the water in oil emulsion to enhance the rubbing fastness as well as soft hand, but the rubbing was still poor [20]. During the Second World War, synthetic rubber latex and butylated melamine-formaldehyde resins were discovered (Figure 2). These two polymeric compounds were *in-situ* with water in oil emulsion, these lead to a significant improvement for rubbing and washing fastness. On the other side, the clean-up of oil emulsion solvents from the printing machine required the use of additional amounts of solvent which created water pollution and final cost [21]. To solve this problem, it would be more appropriate to apply water-based systems for textile printing. The first water-based print systems were oil-in-water emulsions. This means the water became the continuous phase and the pigment as well as binder would be deposited as a continuous film [22].



PAN

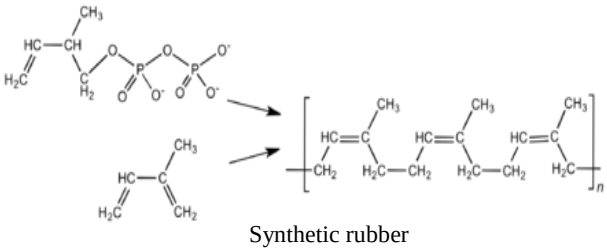
Poly (methacrylic acid co-polymethyl methacrylate)



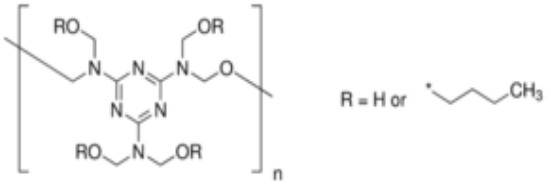
Styrene-butyl acrylate copolymer

Figure 1. Some structure of copolymer of textile pigment printing binder

3. Section 3: Types of binders



Synthetic rubber



Butylated Melamine formaldehyde Resin

Figure 2. Chemical structure of synthetic rubber and butylated melamine formaldehyde resin

Binders that are used for textile printing paste can be classified into two types **i)** reactive and **ii)** non-reactive. Table 1 shows the difference between the two types of binders.

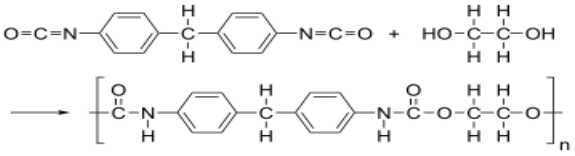
Table 1. Types of binders based on their reactivity

Non-Reactive Binders	Reactive Binders
Do not contain reactive groups	Contain reactive groups
Not self-cross-linkable during fixation or curing	Self-cross-linkable during fixation or curing from copolymerization with monomers
Addition of fixing agent is obligatory	Fixing agent is not required
Can't form a fixed binder film on textile surfaces	It able to form a fixed binder film during fixation

Polymerization is the combination of large number of small molecules (called monomer) to form a macromolecule (called polymer). For examples, acrylic acid and methacrylic acid are simple acrylic monomers that can be polymerized into high molecular weight resins, which in turn form films around the pigments molecule and will adhere to the substrate and thus bind the pigment [23].

The acrylic monomer is the most popular binder in use. These polymers are linear and literally interlock with the pigment and itself into the fiber. On the other hand, the fastness properties of these polymers are not as good as expected, especially for rubbing and washing fastness, such as the binder, which requires more energy to complete the stability process [24].

For example, if the binder contains supplementary sections of the polymer known as branched chains, it can adhere to other sections of the polymer at right angles to the long linear chains. This compound is three-dimensional in nature and it will have relatively high fastness properties, especially for rubbing and washing fastness. Once this compound becomes three-dimensional in nature it becomes more rigid and thus makes the texture stiff [25–27].



Scheme 1: Polyurethane synthesis (the urethane groups –NH-(C=O)-O- react with the molecular units

Printing paste is the main component of printing that allows creation of defined patterns. Generally, pigment printing paste for textile printing contains colorant, binder, thickener, softener, emulsion, crosslinking agent, and anti-foaming agent. So, it's important to grant individual sight to every component of the printing paste. Not all of the above components are used simultaneously in any textile pigment printing paste. Looking on the category of pigment and also the printing method used, the suitable component is assembled into making the printing paste [29].

The binder must be viable and produce other properties to boost the tinting effect of the pigment. It must be cheap, good color yield, un-poisonous, soft, washable, easy to polymerized, no-yellowing, doesn't affect light fastness properties [30].

4. Section 4: Some Innovative technologies in binder synthesis and application in textile printing

5. Hamilton and Chiweshe prepared a binder for textile pigment printing using modified gluten with methyl acrylate group [31]. They used two set styles of fabrics (cotton and polyester fabrics), the 1st set (control sample) was printed with four printing pastes contain different binder types: acrylic, vinyl acetate, and two forms of butadiene acrylic binders. The 2nd set was printed with a printing baste containing a combination from a prepared modified binder with the commercial one by using two different dyes (diarylide yellow and azoic scarlet). Then the printed fabrics were analyses in line with the standard methods. The result showed that: i) the addition of gluten prepared modified binder have good water, solvent, perspiration, and lightweight resistance, ii) poor to rubbing fastness, iii) when the modified gluten added to the co-binder, it increased the stiffness of the printing paste that containing the commercial one, iv) modified gluten increase the viscosity, therefore the reduces the number of thickener needed in printing pastes, and v) modified gluten have good pigment print paste binders for textiles.

From the scientific point of view, the above study lakes some analyses and testing; Viz. Rheological properties, T_g, FTR to approve that the methyl acrylate reacts successfully with gluten or not, fixation factors, and therefore the color strength (K/S) of every printed area.

In 2007, polyurethane acrylate oligomers were prepared from IPDI (isophorone diisocyanate), then mixing with PEG 1000 or 2000 [32]. This mixture was then modified by adding acetone (70%) and sterilized under nitrogen atmosphere in presence of dibutyl tin dilaurate (DBTDL) as a catalyst which was slowly added to 0.0 5% IPDI at 40°C for 60 min. The rheological properties and its utilization as a UV-curable binder for inks in inkjet printing and pigment coloration of various fabrics (cotton, viscose, wool, polyester, and nylon) were investigated. The obtained result showed that the prepared binder is characterized by low viscosity at a rate of shear of 10.0007 S1. The aqueous UV-curable binder of polyurethane acrylate oligomer supported by PEG may be used safely for inks of inkjet printing and also in pigment dyeing. When the binder concentration increased, the colour strength and the fastness properties were improved from good to excellent. The FTIR investigation of the prepared polyurethane acrylate oligomer implied some physicochemical changes within the structure [33]. Although the authors of this work said that the prepared binder is a suitable candidate for dyeing fabrics understudy, yet they failed to perform the dyeing process.

On the opposite side, aqueous binder oligomers of polyurethane acrylate (AUA) supported polyethylene glycol and/or glycerol ethoxylate-co-propoxylate were synthesized and used in pigment printing pastes for various textile substrates [34]. The obtained result proved that there was an

improvement in color strength (K/S), the fastness properties of the printed samples using synthesized polyurethane acrylate. The lowest K/S values were obtained when employing a commercial binder (Ebecryl 2002). The highest colour strength was attained upon using the binder of PUA supported by PEG2000.

In 2012, seven different polyurethane acrylate copolymers were prepared to switch the two (OH) groups on polyethylene glycol by adding specific reagents with liberation of isophorone diisocyanate or toluene diisocyanate group [35]. The remaining isocyanate is combined with either hydroxyethyl acrylate or hydroxypropyl methacrylate to get polyurethane acrylate [PUA] copolymers.

The FTIR spectra confirmed the formation of these products with fully reacted isocyanate groups, while the double bonds remain unaffected and labile for further reaction during fixation process. The synthesized PUA may be classified as soft binders with typical relative molecular mass values of the prepared PUA polymer range between 9.8851e4 and 1.01010e5. The spheres diameters are in the range from 324 nm to 346 nm when subjected to mill for about 5 days, while it below 60 nm when subjected to mill for 15 days. We believe that these findings are promising and novel novelty but it would be better to examine the validity of the synthesized binder lacks to check if these prepared polyurethane in textile printing or not applicable.

El-Molla *et al.* applied a new PU polymer as a textile binder within the pigment printing of polyester employing a flat-screen printing technique. Seven different aqueous PU binders (named b1-b7 irrespectively) were prepared; from which four are based on isophorone diisocyanate, while the rest are dependent on toluene diisocyanate [36]. Binder from b1-b3 was prepared with a unique relative molecular mass of PEG 6000, 12000, and 20000 g/mole + Polyol and hydroxy ethyl acrylate (HEA), while the fourth on b4 was prepared from PUA + PEG 20000 g/mole + polyol and hydroxy propyl methacrylate (HPMA). Binder (b5) was prepared from PUA + PEG 20000 g/mole + polyol +HEA, while binder's b6 & b7 were prepared from PUA + PEG (20000, 6000 g/mole) + polyol +HPMA, respectively. The authors of this study adopted pigment fixation through the polymerization process using two different fixation modes. Either thermo fixation at different temperatures (80, 100, 120, and 160°C) for various times (3, 5, and 10 min) or microwave irradiation at 500 watt for 3, 4 and 5 min. The K/S and the fastness properties of the printed fabrics were dependent on the nature of binder, its concentration, fixation type, time and temperature.

The importance of this investigation is the application of microwave-assisted fixation of prints as an alternative method for the conventional heating one. The use of energy, water, and chemicals-saving processes has positive impact from the economic and ecologic points of views [37–39].

In another investigation, micro-emulsion co-polymer was converted into nanoparticles size (NPS) was prepared by using butyl acrylate (BA)/acrylic acid (AAc) with high monomer/surfactant ratio in the presence of sodium dodecyl sulphate (SDS) as an emulsifier mixed with potassium peroxy disulphate/glucose as an eco-friendly redox initiator. The obtained result proved that the particle size, as well as the stability of the prepared micro-emulsion, relied on the concentration of monomer and initiator that is added to emulsifier content ratios (wt. %), 50/50 AAc/BA gives homogeneous micro-emulsion binder with small particle size. The glass transition temperature (T_g) of the prepared micro-emulsion was ranged from -2.44 to 2.39°C which implies that it can be used as a textile pigment printing binder. TEM proved that the prepared binder in NPs size within the range of 24-48 nm. FTIR analysis showed that the co-polymerization process took place between AAc and BA and the active carboxylic group remains unaffected during the polymerization process. Also, ^{1}H-NMR showed that the appearance of the characteristic signals due to the various protons in the polymer backbone and absence of signal of vinyl proton –C=C-H (5-6 ppm) confirmed the occurrence of co-polymerization between AAc and BA. The prepared micro-emulsion under the optimum condition (50/50 wt. % AAc/BA, 5 g wt. % SDS and 0.2 g wt. % KPS) was investigated and applied as a binder for textile pigment printing onto cotton fabric, polyester and cotton/polyester blend by using a flat-screen. The results approved that the optimum concentration of the binder that gave satisfactory fastness, good handle and high colour yield was 20%. At the optimum curing conditions (160°C for 4 min), there are small differences in the K/S values and fastness properties of the printed cotton, polyester or cotton/ polyester fabrics [40].

Preparation of nano-emulsion co-polymer particles by using different ratio of butyl methacrylate/acrylic acid (BMA/ACA) was carried out. The system adopted a high monomer/surfactant ratio via ultrasonic homogenizer as a new heating source and compared the prepared nano-emulsion with the prepared via the traditional method [41]. The aims of that investigation were extended to study the use of the prepared nano-emulsion as a binder in textile pigment printing pastes.

Although it is a new time, energy, and water-saving technique, yet one of the drawbacks of this investigation is that it is an environment unfriendly method, presumably due to the use of many chemicals during the preparation process.

5. Section 5: Binders based on renewable natural resources

Many substances have been extracted from renewable natural resources and were successfully used in textile applications. These include, among others, biopolymers [42–44], colorants [7, 45], enzymes [46, 47], and fatty materials [48–50]. Synthesis of binder based on renewable natural resources by using sustainable energy to save energy and reducing time has been the ultimate goal and attention of many researchers [51, 52]. Some research work focuses on the potential future applications of microwave irradiation as a new heating source to achieve this goal [53]. Alkyd resins with appropriate characteristics and proper interacting properties, based on available renewable resources, named sunflower and/or soybean oil, were synthesized and characterized. This study introduces a rapid and highly efficient method toward the synthesis of nano-binder from available renewable resources by using either domestic or synthesis microwave irradiation to save energy, time, water as well as enhance the end-use properties of printed textile to demand the customers' need.

6. Section 6: Synthetic binders

Synthetic binders are widely used in pigment printing of textiles by virtue of their convenient properties [54]. An aqueous polyurethane acrylate binder was successfully synthesized and employed for pigment fixation using flat-screen technique to print cotton. The K/S values of the printed fabrics depended on the chemical structure of the binder, nature of the printed fabric, and binder concentration. The fastness properties of the printed fabric were very good especially rubbing fastness [53].

The color performances of disperse dye washing-free printing have tight connections with the solubility parameters of polymer binders. Ethyl hexyl acrylate (EHA) and methyl methacrylate (MMA) were selected as monomers to prepare a series of polyacrylate (PA) binders by using mini-emulsion polymerization. The effects of emulsifiers and the EHA-MMA ratios on PA properties were evaluated. The obtained data showed that PA emulsion became more stable, smaller particle size further as distribution, and better tensile strength at the ratio of sodium lauryl sulfate: fatty alcohol polyoxyethylene ether (O-10): propylene oxide propyl alkyl phenyl polyether ammonium sulfate (V-20S) of 1.5:1:1. This mixture was added to the printing paste in a ratio of 6% (v/v). This method resulted in reduced breaking strength, enhanced elongation, and improved adhesive power. The color yield of the washing-free printed polyester fabric was improved to different extents depending on the ratio between the said monomers and the disperse dye. PA achieved the best mechanical and washing-free printing properties at the mass ratio 11:9 (EHA: MMA) of (55 wt. % EHA) [52].

In another investigation, silicone was introduced to improve the weathering resistance of the printed fabric and enhancing the mechanical as well as the physical properties of ethyl acrylate polymer which was used as a binder for textile pigment printing [53]. This was brought about by co-polymerization of ethyl acrylate with butyl acrylate in presence of acrylic and/or methacrylic acid as shown in Figure 3.

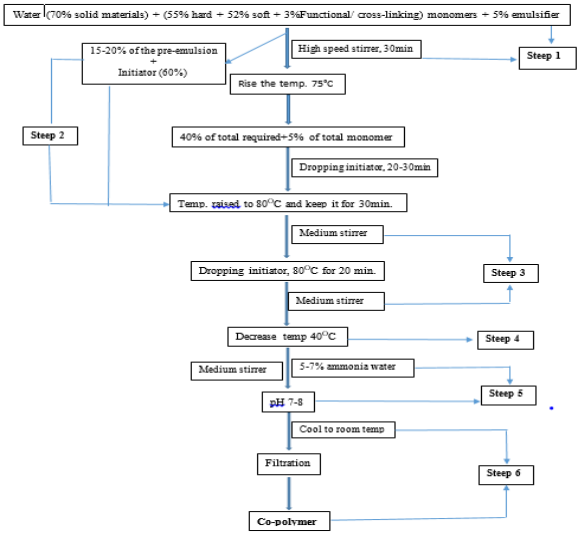


Figure 3. Synthesis of silicon-based binder

It has been concluded from this investigation that as the amount of silicon increased, the gel quality as well as the solid content, were slightly increased. The unreacted Si-OH groups, through the polymerization process, form hydrogen bond or other bonds due to cohesive force. The polymerization time shouldn't overrun 150 min. Particles in the aqueous emulsion were well distributed, and the average particle size was ranged from 49-120 nm. No change was monitored in dilution, electrolyte resistance, thermal, acid, and alkali stability at pH 7-8. Upon application of the prepared binder on white plain-woven cotton fabric by using the rotary screen printing method, it was observed that there is an enhancement in sublimation, durability, rubbing fastness, staining resistance and softness performance of the cotton printed fabrics [55]. One of the drawbacks of this method is that it is a multi-step processes and consumes a huge amount of energy and time.

7. Section 7: Biopolymer-based binder

Many biopolymers have been utilized in textile industries either as a starting material for preparation of textile auxiliaries or to enhance the performance attributes of textile fabrics. These include, among others, keratin, sericin, gelatin, starch, and chitin [56–

[59]. Recently, keratin was used to prepare an eco-friendly binder used in pigment printing of textile fabrics. Figure 4 shows a flow chart for preparation of keratin-based binder from raw material [60]. The prepared keratin-based binder is eco-friendly and cost effective. It was successfully utilized in pigment of polyester, polyacrylonitrile, viscose as well as polyester/viscose, and polyester/acrylic blends. This binder is a benign alternative to the commercial synthetic binders which are conventionally used in pigment printing of textiles. The chemical, physical, and thermal characteristics of the synthesized binder were evaluated and compared with the commercial one. The effect of the used binder on the color strength (K/S), and the bending stiffness of the printed area of each fabric, and their fastness properties were evaluated.

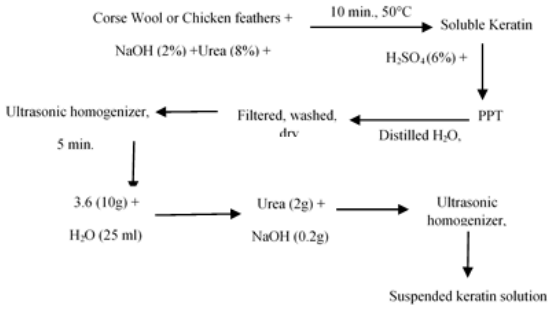
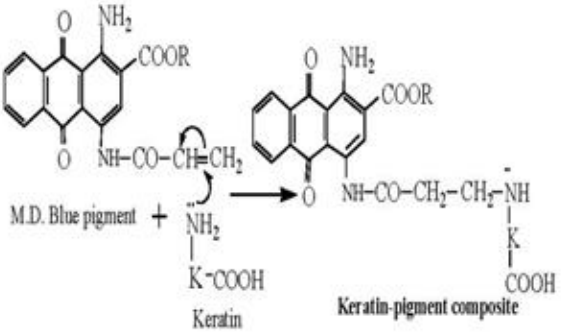


Fig. 4: Schematic diagram for preparation of keratin-based binder

The highest K/S values and fastness properties of the pigment-printed samples using keratin-based binder were obtained upon using cross-linker such as glutardialdhyde. For the same printing operation, the K/S values of the printed fabrics using keratin-based binder are similar to those obtained upon using commercial binder. All printed fabrics exhibit good fastness properties to light, wash and perspiration.

The rheological measurements of the printing pastes containing keratin-based binder revealed that this type of printing paste pastes are a non-Newtonian pseudoplastic. The water absorption of the keratin-based binder film is higher than that of the commercial binder.



Scheme 2: Reaction mechanism between M.D. Blue 2G pigment and keratin.

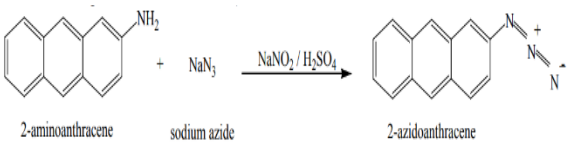
Keratin macromolecule can bind with M. D. Blue pigment via Michael addition reaction between the electron donor amino group of keratin and the electron acceptor olefinic double bond in the said pigment (scheme 2). The carboxylic and amino groups along the keratin macromolecules are the reactive sites which can bond with the textile substrate subjected to the printing process.

8. Section 8: New trends in synthesis of binders

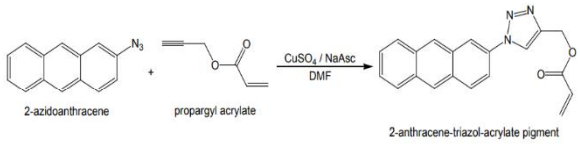
The preparation of new green binders using rapid and highly efficient method in a simple reaction is of prime importance from the technical, ecologic and economic points of views. More important is the feasibility of industrial-scale production of the proposed binder.

Schemes 3 and 4 show the synthesis of new unsaturated pigment, 2-anthracene triazole acrylate, via click reaction was represented [61]. The prepared pigment was considered as a monomer and was copolymerized with acrylic acid and butyl acrylate, so it would be a part of the binder chain and it is considered as a colored binder for pigment printing for different fabrics. Particle size, particle size distribution, glass transition temperature (T_g), stiffness as well as rheological properties were analyzed to evaluate the feasibility of using the prepared pigment as a colored binder in textile pigment printing [62].

In another investigation, polyurethane turf adhesive was synthesized by reacting diisocyanate and polyol (petroleum-based polyether) [63]. This polyol can be substituted by a cost-effective natural oil; namely soybean oil [64]. The soybean was subjected to epoxidation followed by oxirane ring-opening in presence of a catalyst (methyl alcohol and orthophosphoric acid) to produce -OH groups in the soybean oil which are capable of reacting chemically with the labile diisocyanate groups. The iodine value of the modified soybean oil decreased significantly, presumably due to conversion of carbon-carbon double bonds into oxirane rings (Figure 5).



Scheme 3: Preparation of 2-azidoanthracene



Scheme 4: Preparation of 2-anthracene triazole acrylate pigment

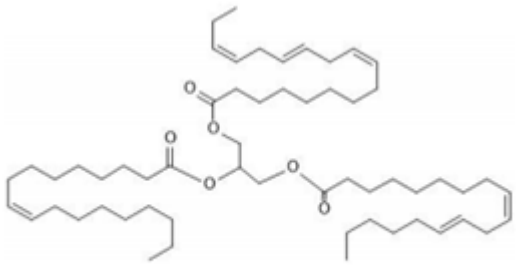


Figure 5. Chemical structure of soybean oil containing unsaturated fatty acids connected to a glycerol centre

The utilization of cheap renewable natural resource (soybean oil) in the preparation of polyurethane adhesive has positive impact from the economic and ecologic points of views. On the other hand, this research needed more measurements and some applications to know if it could be used as a binder for textile pigment printing or not.

In another investigation, nano-emulsion polyurethane-acrylic (PUA) hybrid from core-shell was synthesized via semi-batch emulsion copolymerization of the acrylate monomers in the presence of a commercial polyurethane dispersion. The synthesized latex was successfully utilized as a binder in textile pigment printing [65]. The transmission electron micrographs of the prepared emulsion with different acrylic/polyurethane ratios are shown in Figure 6. Further investigation should be carried out to assign the feasibility of using the synthesized material as a binder in pigment printing of textile fabrics.

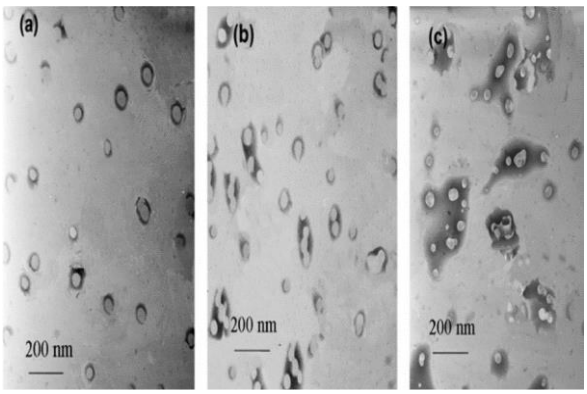


Figure 6. TEM images of Acrylic–polyurethane hybrid emulsion with polyacrylic/polyurethane ratios of (a) 40/60 (PUA 40), (b) 60/40 (PUA 60) and (c) 80/20 (PUA 80)

Adopting a pre-polymer mixing process, two polyurethanes were efficaciously synthesized by the step-growth addition polymerization of polypropylene glycol, methylene diphenyl diisocyanate and 2-hydroxyethyl methacrylate or 2-hydroxyethyl acrylate, in presence of isopropyl alcohol as a blocker for the isocyanate. Afterwards, terpolymer emulsions were prepared by emulsion graft copolymerization with vinyl acetate in presence of 2-ethylhexyl acrylate [65, 66]. It was concluded the thermal stability of vinyl acetate copolymer was highly improved in presence of polyurethane moiety. The methacrylate based-terpolymers exhibited lower thermal stability than acrylate-based ones. The printed textile fabric fabrics, in presence of the synthesized binder, have better color strength, rubbing fastness, washing fastness and soft handle. In our opinion, further studies are required to accelerate the rate of reaction and to decrease the particle size of the synthesized oligomers.

A core-shell acrylate binder, suitable for pigment printing, involving 2-(methacyloxy) ethyl acetaoacetate (MEA) in its shell was synthesized through semi-continuous seeded emulsion polymerization [54]. Self-crosslinking of MEA takes place by curing at relatively low temperatures without emission of formaldehyde. The crosslinking reaction was induced between diamines (amino silicone oil) and the remaining acetoacetyl groups in the MEA. The synthesized binder was formaldehyde-free, eco-friendly, and it could self-crosslink when curing at 100°C. The fastness properties as well as softness of the prints were improved Fig.7.

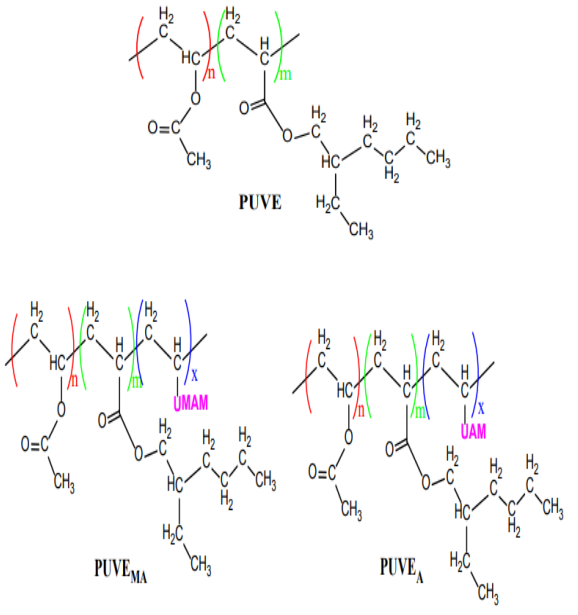


Fig. 7 Suggested chemical structures of the PUVE, PUVEMA, and PUVEA polymers.

9. Conclusions

The technology of textile printing in different industries provides several benefits. Binder, in particular, has a huge potential for improving products and the textile industry. The new technologies in textile printing are starting to get attention due to its smart functions in producing new materials as well as accelerate a great number of chemical processes in an eco-friendly way, especially, it decreases the synthesis time and energy that are run for a long time at high temperatures under classical techniques, this makes binder synthesis easily to cover the request of the high demand growing market. In addition, the demand for eco-friendly textile production techniques will support more studies in the usage of the new technology on an industrial scale, which help in reducing the pollution emitted from chemicals used in binder preparation as well as improving them.

New technology encompasses environmental characteristics as a reduced byproduct, water and energy are conserved, as well as time and costs are saved. Last but not least, the study of using the new technology in the binder synthesis will get more attention to make it possible to use in small-scale enterprises to the textile sector and are a promising area for interesting research.

Conflicts of interest

"There are no conflicts to declare".

10. Formatting of funding sources

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