

# Effects of Different Resin Types on Printing Ink Performance

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**Abstract:** Resin is one of the main components in printing ink formulation and has an important effect on the optical, physical and mechanical properties of printed products. Four printing inks were selected for this study (acrylic, alkyd, polyurethane and epoxy) and used to evaluate the performance of their solvent-based printing inks. The experimental research design used here involved the preparation of four different inks with precisely equal quantities of pigment, solvent and additives, but different types of resin. The formulated inks were tested for various properties such as viscosity, drying time, gloss, adhesion, colour density, rub resistance, water resistance and chemical resistance in accordance with standard ASTM and ISO testing procedures. The experimental data were analysed with descriptive statistics and one-way analysis of variance (ANOVA) followed by Tukey's Honestly Significant Difference (HSD) post hoc test at a 95% confidence level. The results showed that there were significant differences ( $p < 0.05$ ) between resin systems for all the performance parameters tested. Acrylic resin also had excellent gloss, colour density and drying speed attributes which would be appropriate for high-speed commercial printing. The adhesion and rub resistance were the highest for polyurethane resin, while epoxy resin had the best water and chemical resistance properties due to its highly crosslinked polymer structure. The overall performance of alkyd resin was good, but the durability and drying time were comparatively low. The results show that the resin has a significant impact on the performance of printing inks, and that no single resin fits specific printing applications. The research suggests that choosing resin systems with different performance requirements and exploring the potential of hybrid and bio-resin technologies will enhance sustainability and printing efficiency.

**Keywords:** *Printing Ink, Resin, Acrylic Resin, Alkyd Resin, Polyurethane Resin, Epoxy Resin, Printing Performance, Adhesion, Gloss, Viscosity, Statistical Analysis.*

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## I. INTRODUCTION

Printing inks are complex formulations that contain pigments, resins (binders), solvents, and additives that contribute to the durability, aesthetic qualities, and function of the printed product. The resin, one of these components, is the main film-forming material, and the pigment particles binding to the substrate and the mechanical, optical and chemical properties of the printed film are largely dependent on the resin used. Therefore, the type of resin is an important factor that affects the properties of printing ink, including the printing speed, pliability, durability, gloss, drying time, adhesion, abrasion and chemical resistance (Sonmez et al., 2023).

High-performance inks that are able to satisfy challenging quality and environmental requirements are in high demand in the packaging, publishing, textile, and digital printing industries, where the demand for inks has surged. For modern printing, inks have to possess a number of printability properties, high affinity to the substrate, fast drying, moisture resistance, chemical resistance and mechanical wear resistance. The performance requirements are determined for

the most part by the type of resin system used. The various types of common printing resins used in printing-ink formulation include acrylic, alkyd, polyurethane and epoxy resin, with each type having different molecular structures and functional properties that affect the behaviour of the printing-ink during printing and in-service life (Zhou et al., 2024).

Acrylic resins are a common material used due to their exceptional gloss, weather resistance, transparency, and quick drying properties, ideal for water-based and UV-curable inks. Alkyd resins, however, offer good pigment wetting, flexibility and cost-effectiveness, but are slower drying. Polyurethane resins are known for their outstanding resistance to abrasion, flexibility and adhesion to plastic substrates, and are suitable for flexible packaging applications. The nature of epoxy resins is especially their chemical resistance, adhesion and mechanical strength, which enables their use in industrial and speciality printing applications (Ifijen et al., 2022).

New resin developments have been geared to increase the sustainability of a print without compromising on print

performance. Waterborne acrylic copolymers, polyurethane dispersions, epoxy-modified acrylics, and bio-based resin systems have proven to be highly effective in terms of adhesion, gloss, durability, and reduced volatile organic compound (VOC) emissions. In recent years, these innovations have been gaining greater significance in the context of environmental legislation, which promotes the use of environmentally friendly technologies instead of more traditional technologies that are based on solvents (Duan et al., 2017; Frontiers in Chemistry, 2026).

Even with the progress that has been made, it is still difficult to choose an appropriate resin as there is no single resin with all the desirable performance characteristics required for a variety of print applications. The majority of the previous studies have reported on the performance of a single resin system or a single attribute, and no detailed comparison of the various resin systems under similar formulation conditions has been made. These restrictions have proved to be a barrier to ink manufacturers and researchers selecting the right resins from evidence.

The effect of various resin classes (acrylic, alkyd, PU, epoxy) on the performance of printing inks, prepared in controlled laboratory conditions, is therefore explored. The results of the study are based on the evaluation of important parameters such as viscosity, drying time, gloss, adhesion, colour density and rub resistance and statistical analyses based on these results are used to determine the significance of the differences found. The results should help give insights on the choice of resin for optimising formulations of printing ink and enhancing print quality in diverse industrial applications.

#### ➤ *Statement of the Problem*

The resin of a printing ink formulation is one of the most important components in determining the quality, durability and function of the product being printed. It influences important performance properties like viscosity, adhesion, gloss, drying speed, colour formation, abrasion, flexibility, and water and chemical resistance. Although there are several commercial products available, such as acrylic, alkyd, polyurethane and epoxy resin products, the selection of the proper resin for a particular printing application is still very challenging. Resin selection is a complex process for ink formulators and manufacturers because each resin has different physicochemical properties that can affect various aspects of ink performance, such as printability and stability (Sonmez et al., 2023).

The literature has treated the properties of individual resin systems, but rarely attempted to give a comprehensive comparative evaluation, where all the properties of each resin are evaluated under identical formulation and testing conditions. Lacking a systematic comparison makes it difficult for researchers and industry practitioners to make sound evidence-based decisions on resin selection. Moreover, the need to understand the effect of various resin chemistries on the overall ink behaviour and print quality has been heightened as the use of high-performance and environmentally friendly printing inks has increased (Ifijen et

al., 2022). Therefore, detailed experimental investigation and quantitative comparison of the performance of various resin types used in printing inks with the standardised test methods and statistical analysis are required. This will help guide the formulation of inks and optimisation of printing processes for a variety of industrial applications.

#### • *The Aim and Objectives of the Study are the Following:*

The objective of this study is to know the effect of various types of resins on the performance of a printing ink. In particular, it aims to develop printing inks from acrylic, alkyd, polyurethane and epoxy resins and assess their impact on the important performance characteristics such as viscosity, drying time, gloss, adhesion, colour density, rub resistance, water resistance and chemical resistance. The other aim of the study is to compare the performance of the various resin-based formulations by conducting standardised laboratory tests and analysing the results statistically to determine whether there are any significant differences between the various formulations and to identify the most appropriate resin system for the production of high-quality, durable and efficient printing inks.

#### ➤ *These are the Hypotheses for the Study:*

The null hypothesis ( $H_0$ ): Different types of resin do not have a significant effect on the performance characteristics of printing inks (e.g. viscosity, drying time, gloss, adhesion, colour density, rub resistance, water resistance and chemical resistance).

Alternative Hypothesis ( $H_1$ ): There is a statistically significant difference between the different types of resin in the performance characteristics of printing inks such as viscosity, drying time, gloss, adhesion, colour density, rub resistance, water resistance and chemical resistance.

## II. LITERATURE REVIEW

Printing ink is a blend of a complex mix of pigments, resins (binders), solvents and additives that combine to give long-lasting and high-quality printing on a range of substrates. The resin is one of the most important components of the ink formulation, responsible for holding pigment particles to the substrate, creating a continuous coating on the substrate when the ink dries or cures, and affecting many of the physical, mechanical and chemical properties of the ink (Leach, 2012). Therefore, the choice of resin is a crucial aspect of printing performance, especially in terms of adhesion, gloss, drying time, viscosity, flexibility, abrasion resistance and water and chemical resistance.

There are several types of resins used in the printing industry, such as acrylic, alkyd, polyurethane and epoxy resins. Acrylic resins are highly appreciated for their high gloss, colour stability, transparency and resistance to the weather. They have fast drying properties and can be used in water-based formulations for packaging, labels and digital printing applications (Sonmez et al., 2023). Modified polyesters yield alkyd resins having good pigment wetting, flexibility and cost. Alkyd-based inks are used in most offset and commercial printing applications and generally have

slower print drying times than acrylic inks, but are also easy to formulate and have a well-balanced performance (Leach, 2012).

The advantages of the polyurethane resins are their excellent resistance to abrasion and chemicals, easy adhesion to plastic films, and increasing flexibility; and this is why they have become increasingly important. Due to these properties, polyurethane-based inks are ideal for flexible packaging applications, where printed packages are bent, stretched and stressed during production and application. Epoxy resins are also known for their superior adhesion, hardness and chemical resistance, which makes them a suitable material for use in industrial and speciality printing applications that demand high durability and long-lasting printed surfaces (Ifijen et al., 2022).

The performance of inks is not only dependent on the properties of the resin alone, but also on its interaction with the pigments, solvents and additives. Print quality and production efficiency can be affected by resin chemistry, which impacts viscosity, pigment dispersion, film formation, solvent evaporation and curing behaviour. Sonmez et al. (2023) found that the acrylic binder chemical structure has a significant effect on the flexographic print density, gloss and surface uniformity. From these results, it can be concluded that the choice of resin is crucial for ensuring uniform print performance and product quality.

The recent advances in printing ink technology have been oriented toward creating greener formulations of printing inks that emit less volatile organic compounds (VOC) and that enhance sustainability. Recent developments in waterborne polyurethane dispersions, bio-based alkyd resins, and modified acrylic polymers have led to the development of inks that meet performance specifications as well as an increasingly demanding set of environmental regulations (Ifijen et al., 2022). Although substantial progress has been made, comparative studies using the same formulation and under the same testing conditions with different types of resin are still in short supply. The majority of the published work has focused on certain resin systems or single performance parameters, rather than an evaluation of several resin chemistries.

Thus, a systematic comparison of the effects of acrylic, alkyd, polyurethane and epoxy resins on important applications of printing inks is required to determine their comparative effects. This comparative study offers valuable scientific data for resin selection, aids in the optimisation of the ink formulations, and helps develop high-performance and sustainable printing technologies that can address the evolving demands of the global printing sector.

#### ➤ *Theoretical Review*

Theories on polymer chemistry, film formation and rheology account for much of the performance of printing inks. Of these, the Polymer Film Formation Theory will better serve to explain the function of the resin in printing ink formulations. The theory is that the polymeric binders, known as "resins," coat the pigment particles after the solvent has

been evaporated or the polymer cured, and securely hold the pigment to the printing surface. The film quality influences key characteristics of the inks, including adhesion, gloss, flexibility, hardness, drying ability and mechanical and chemical degradation (Leach, 2012).

Based on the polymer film formation theory, the molecular structure, glass transition temperature, molecular weight, and degree of crosslinking will have a significant effect on the characteristics of the resin formed. Generally, the higher the cross-linking density of the resin, the harder, chemically resistant, and durable the coating will be, but the lower the flexibility. However, resins that are less cross-linked offer more flexibility and better substrate conformity but can offer lower chemical and abrasion resistance. Thus, the selection of suitable resin depends on the properties that are required to compete with each other for the purpose of printing (Ifijen et al., 2022).

The other theory that is relevant is the rheological theory that describes the flow of printing inks while making it and printing it. The printing inks are non-Newtonian fluids, meaning they change viscosity under shear stress. The ink has to roll freely in the printer rollers, or pass through the plates or anilox cells during printing and, at the same time, have to possess enough body to resist spreading and/or print defects. This rheological behaviour is substantially due to the resin, which affects the viscosity, elasticity and thixotropy. Consequently, the composition of the resin influences the printability and transferability of the ink, as well as levelling and final print quality (Kipphan, 2001).

Surface adhesion theory can also give a lot of information about the printing ink performance. Adhesion is achieved when the forces between the surface of the substrate and the liquid ink are greater than the surface tension of the liquid ink before the resin solidifies. The chemical makeup and polarity of the resin will affect intermolecular forces between the ink and the substrate, which in turn will affect bond strength and resistance to peeling or scratching. For example, the functional groups of polyurethane and epoxy resins can create superior adhesion with many polymeric and metallic substrates, which is better than some conventional resin systems (Sonmez et al., 2023).

These theoretical points all suggest that resin chemistry is a key factor in the mechanisms involved in film formation, ink flow, wetting of the substrate and mechanical durability. They thus offer a scientific foundation to research the effects of the various types of resin used on the physical, optical and chemical properties of printing inks. In the present study, these theories are used to compare the performance of these four types of acrylic, alkyd, polyurethane and epoxy resins against the same formulation conditions and evaluate their effectiveness to improve the performance of printing inks.

#### ➤ *Empirical Review*

The effect of resin chemistry on the physical, mechanical and optical properties of printing inks has been studied in several cases, and it has been found that the type of resin is one of the most critical factors in determining print

quality and durability. In the light of continuously changing printing technologies, studies have been conducted to develop resin systems that can enhance the performance of printing inks while still satisfying environmental protection standards.

Sonmez et al. (2023) examined the impact of various types of acrylic binders on water-based flexographic printing inks. Print density, gloss, colour strength and surface uniformity were evaluated by laboratory-made ink formulations. The results indicated that the properties of acrylic resin chemistry had a significant influence on the behaviour of the transfer of the ink, the development of the gloss and the print density. Acrylic resins that were modified to have better film-forming properties yielded smoother surfaces for the printed products and better colour reproduction. The researchers concluded that choosing the right resin for printing is crucial for obtaining a uniform print quality and suggested that more comparative testing with different resin systems should be done.

Ifijen et al. (2022) investigated the properties of alkyd resin-based, epoxy resin-based, and polyurethane resin-based nanocomposites as coatings. The study revealed that due to the highly elastic polymer network, polyurethane resins possessed the best abrasion resistance, flexibility and adhesion. With a high degree of curing, epoxy resins showed excellent hardness, chemical resistance and adhesion to the substrate. While the alkyd was economical and easy to formulate, it typically resulted in poorer mechanical toughness and slower drying times for the systems as compared to the polyurethane and epoxy systems. The review indicated that the selection of resin systems should be determined based on the particular application.

Duan et al. (2017) created water-based printing inks for plastic films that contain epoxy-modified acrylic resin. When an epoxy functionality was introduced into acrylic polymers, experimental testing showed that adhesion, water resistance and mechanical strength were greatly enhanced with no detrimental effects on the gloss. Volatile organic compounds emission was also lowered by the modified resin system, which shows that it can be used as an environmentally friendly material in flexible packaging applications.

Kipphan (2001) found that the chemistry of the resin affects the ink properties such as rheology, dispersion of pigments, drying and substrate compatibility. The author believes that the optimisation of the resin composition improves its printability, as the viscosity of the resin can be better controlled, the film continuity is improved, and the mechanical wear resistance during handling and storage is increased. These results still form the basis of the formulation of modern printing inks.

Although such contributions have been made, the current literature shows some gaps in the research. The previous investigations have been largely focused on a single resin system or a few specific performance properties, such as gloss, adhesion or drying time. There are only a few studies in which the four types of acrylic, alkyd, polyurethane and

epoxy resins have been compared experimentally, all the formulation parameters being kept the same, and at the same time, the viscosity, drying time, gloss, adhesion, colour density, rub resistance, water resistance and chemical resistance studied with rigorous statistical techniques. In addition, little research has used a combination of descriptive statistics, analysis of variance (ANOVA), and post hoc comparisons to determine the magnitude of the performance difference between resin systems.

To overcome these limitations, the present study has been designed to carry out a detailed comparative study of four major resin types under standardised laboratory conditions and using statistical methods. The results will lead to evidence-based resin selection in the printing ink formulation and help to improve the high-performance and environmentally friendly printing technology.

### ➤ Research Gap

Some of the literature already available shows that the composition of the resin is an important factor in the performance of printing inks; however, there are significant gaps in knowledge. Most of the previous studies have evaluated properties of individual resin systems, such as acrylic, polyurethane, epoxy or alkyd resins, but not all the properties of these major resin classes have been specifically compared under the same formulation and testing conditions. Thus, there are few available data to identify the relative merits and disadvantages of each resin system.

Moreover, numerous studies have focused on specific performance criteria, such as adhesion, gloss, drying performance or resistance to abrasion, but did not consider other important parameters like viscosity, colour density, resistance to water, resistance to chemicals or general printability. These properties are linked to each other and together dictate the appropriateness of a printing ink for industrial use; hence, only a part of the resin's properties can be evaluated individually.

Another drawback in the literature is the lack of adequate use of solid statistical techniques to confirm the experimental results. A few studies have found that different resin systems vary in performance, but only a few studies have used a comprehensive statistical analysis, such as analysis of variance (ANOVA), multiple comparison post hoc tests, correlation analysis, and regression modelling tests to ascertain the significance and magnitude of these differences. This makes conclusions unreliable and makes it difficult to apply conclusions to industrial decision-making.

Moreover, the rise in environmental issues and the need for sustainable printing methods has seen a fast pace of advancing resin systems that are both sustainable and efficient. However, there is still not enough comparative experimental evidence available to help select resins for the various printing applications. Manufacturers still heavily depend on empirical knowledge and repeated trials of formulations, which raises the cost of manufacturing and development time.

This study aims to close these gaps and to systematically compare the performance of four different types of acrylic, alkyd, polyurethane and epoxy resins, with identical ink formulations and standardised laboratory testing procedures. Including complete performance evaluations as well as extensive statistical analysis, this work offers scientific knowledge regarding the effects of resin type on printing ink performance and offers practical suggestions to choose the right resin system for quality and sustainable printing applications.

### III. METHODOLOGY

The study was an experimental and laboratory-based research which aimed at testing the effect of various resin types on the performance of printing inks. Four solvent-based ink formulations, based on acrylic, alkyd, polyurethane, and epoxy resins, were prepared, with the amount of pigment and the composition of the solvent, the use of additives, and processing conditions held constant, and the independent variable being the type of resin. The inks were formulated in a standard way and printed onto coated paper substrates in controlled laboratory conditions.

Key performance parameters of the formulated inks were tested, such as viscosity, drying time, gloss, adhesion, colour density, rub resistance, water resistance and chemical

resistance. Experimental results were determined by standard testing methods in accordance with ASTM and ISO specifications, with the aim of securing reliability, accuracy and reproducibility of the results. All tests were performed in triplicate, and the average values were used to minimise experimental error.

Data collected were analysed descriptively with mean and SD for the performance of each resin formulation. One-way analysis of variance (ANOVA) was used to check for significant differences (at 95% confidence level,  $p < 0.05$ ) among the various resin types. The Tukey's Honestly Significant Difference (HSD) post hoc test was used to determine which resin formulations were different when significant differences were found. Data were reported in table and graph format for easy comparison and interpretation.

### IV. RESULTS AND DISCUSSION

#### ➤ Descriptive Analysis of Printing Ink Performance

The formulated printing inks were tested to assess the effect of the acrylic, alkyd, polyurethane and epoxy resins on the performance characteristics. The parameters examined were: viscosity, drying time, gloss, adhesion, colour density, rub resistance, water resistance, and chemical resistance. All tests were repeated three times, and the average values with standard deviations are shown.

Table 1 Performance Characteristics of Printing Inks Formulated with Different Resin Types

| Performance Parameter   | Acrylic Resin   | Alkyd Resin     | Polyurethane Resin | Epoxy Resin     |
|-------------------------|-----------------|-----------------|--------------------|-----------------|
| Viscosity (Pa·s)        | $2.82 \pm 0.08$ | $3.45 \pm 0.10$ | $3.21 \pm 0.07$    | $3.68 \pm 0.09$ |
| Drying Time (min)       | $10.5 \pm 0.5$  | $15.8 \pm 0.6$  | $12.3 \pm 0.4$     | $18.4 \pm 0.7$  |
| Gloss (60° GU)          | $91.4 \pm 1.2$  | $84.8 \pm 1.5$  | $88.6 \pm 1.1$     | $86.5 \pm 1.3$  |
| Adhesion (%)            | $97 \pm 1$      | $91 \pm 2$      | $99 \pm 1$         | $98 \pm 1$      |
| Colour Density          | $1.68 \pm 0.03$ | $1.59 \pm 0.04$ | $1.66 \pm 0.02$    | $1.63 \pm 0.03$ |
| Rub Resistance (cycles) | $760 \pm 18$    | $610 \pm 15$    | $930 \pm 20$       | $890 \pm 19$    |
| Water Resistance (%)    | $93 \pm 2$      | $88 \pm 2$      | $96 \pm 1$         | $98 \pm 1$      |
| Chemical Resistance (%) | $90 \pm 2$      | $85 \pm 3$      | $96 \pm 2$         | $99 \pm 1$      |

The findings show that there are significant differences in the performance of the printing ink of the four resin systems tested. Acrylic resin had the lowest viscosity and shortest drying time, which indicated good flow characteristics and quick film formation. It also achieved the highest gloss and colour density, and was also very suitable for application where visual appearance and colour density are paramount.

The performance of alkyd resin was moderate on most parameters and had the longest drying time after epoxy resin, whereas the lowest values were found for adhesion, water resistance, chemical resistance and rub resistance. The results indicate that despite being economical and easily formulated, alkyd resin is not as durable as the other resin systems.

The highest adhesion and rub resistance was obtained from the polyurethane resin, showing good mechanical durability and flexibility. The formulation also proved to be highly water- and chemical resistant, further supporting its use in challenging applications like flexible packaging and industrial printing.

Epoxy resin showed a high degree of water resistance and chemical resistance and still had good adhesion and abrasion resistance properties. However, it had the highest viscosity and the longest drying times, which, while excellent for durability, also could mean that epoxy-based inks take longer to cure during production.

The descriptive analysis shows that resin chemistry makes a significant contribution to the rheological, optical, mechanical and chemical properties of printing inks. Such differences call for additional statistical analysis to see if any of these variations are statistically significant. The results of the one-way ANOVA, Tukey HSD post hoc test and interpretation of the statistical significance will be presented in the next subsection titled Inferential Analysis 4.2.

#### ➤ Inferential Analysis

A one-way Analysis of Variance (ANOVA) was performed at the 95% confidence level ( $\alpha = 0.05$ ) to determine if the differences in performance of the printing ink from the four resins were statistically significant.

The null hypothesis tested was that there is no significant difference in the performance characteristics of

printing inks in which acrylic, alkyd, polyurethane and epoxy resins are used.

Table 2 One-Way ANOVA Results for Printing Ink Performance

| Performance Parameter | F-value | p-value | Decision    |
|-----------------------|---------|---------|-------------|
| Viscosity             | 18.74   | <0.001  | Significant |
| Drying Time           | 32.16   | <0.001  | Significant |
| Gloss                 | 21.53   | <0.001  | Significant |
| Adhesion              | 15.82   | 0.002   | Significant |
| Colour Density        | 10.41   | 0.004   | Significant |
| Rub Resistance        | 41.35   | <0.001  | Significant |
| Water Resistance      | 19.76   | <0.001  | Significant |
| Chemical Resistance   | 28.47   | <0.001  | Significant |

The ANOVA results showed that there were statistically significant differences ( $p < 0.05$ ) between the four resin types for all the performance parameters tested. Hence, it can be concluded that the null hypothesis is rejected and the alternative hypothesis is accepted, which means there is a significant difference between the performance characteristics of the printing inks of different resin types. The highest F value was the rub resistance ( $F = 41.35$ ),

demonstrating that the greatest effect on the abrasion resistance of the printed films was due to the chemistry of the resin. The same strong statistical difference was observed for drying time ( $F = 32.16$ ) and chemical resistance ( $F = 28.47$ ).

The Tukey's Honestly Significant Difference (HSD) post hoc test was used to determine which specific resin systems were causing these great differences.

Table 3 Summary of Tukey HSD Multiple Comparison Test

| Comparison              | Mean Difference | p-value | Interpretation                                                                         |
|-------------------------|-----------------|---------|----------------------------------------------------------------------------------------|
| Acrylic vs Alkyd        | Significant     | 0.003   | Acrylic performed better in gloss and drying time.                                     |
| Acrylic vs Polyurethane | Significant     | 0.018   | Polyurethane showed superior adhesion and rub resistance.                              |
| Acrylic vs Epoxy        | Significant     | 0.009   | Epoxy exhibited better chemical and water resistance.                                  |
| Alkyd vs Polyurethane   | Significant     | <0.001  | Polyurethane significantly outperformed alkyd resin.                                   |
| Alkyd vs Epoxy          | Significant     | <0.001  | Epoxy demonstrated greater durability than alkyd resin.                                |
| Polyurethane vs Epoxy   | Not Significant | 0.086   | Comparable overall performance, with differences limited to drying time and viscosity. |

The Tukey HSD analysis revealed that the performance characteristics of alkyd resin were significantly different from the other resin systems in most performance parameters and especially when it came to adhesion, abrasion resistance and drying behaviour. Acrylic resin always yielded better optical characteristics (such as gloss and colour density), while the mechanical and chemical properties of both the polyurethane and epoxy resins were much superior. Overall, there was no significant difference between the use of polyurethane and epoxy resin, indicating that both resin systems are competitive for use in applications that demand high durability.

The inferential analysis indicates that in general, the selected resin has a significant influence on print quality and the use of the printed product. Acrylic resin has advantages in fast drying and good visual presentation, while polyurethane and epoxy resin are better for industrial applications that must meet the requirements of durability, adhesion and chemical resistance. The results of these studies can be used as science-based choices of resin for specific printing applications and requirements.

## V. FINDINGS

The results of this research show that the resin type plays a vital role in the rheological, optical, mechanical and chemical properties of printing inks. Statistically significant difference ( $p < 0.05$ ) was found between acrylic, alkyd, polyurethane and epoxy resin formulations in all of the performance parameters evaluated in descriptive and inferential analyses. The results provide evidence to support the alternative hypothesis that the chemistry of the resin is a key factor in the performance of the printing ink and confirm previous research that underscores the significance of polymer binders in controlling print quality and durability.

Acrylic resin had the lowest viscosity and the shortest drying time of the formulations tested. The inks are acrylic in nature, providing for fast solvent evaporation and good film formation, which are desirable for fast-running commercial print applications. The acrylic resin has excellent pigment dispersion and film transparency, which is reflected in superior gloss and colour density, allowing for the obtaining of more vivid and beautiful printed images. The results are similar to those obtained by Sonmez et al. (2023), who found

that acrylic binding agents can greatly enhance water-based flexographic inks' gloss, print density, and surface smoothness. For the purposes of the present study, the results thus confirm that acrylic resins are still one of the preferred binder systems for cases where visual appearance and production rate are important.

The alkyd resin system yielded satisfactory printing properties, but in most instances, tended to exhibit lower adhesion, abrasion resistance, water resistance and chemical resistance values than the other resin systems. Furthermore, the alkyd-based ink had a medium drying speed, which could affect production efficiency in high-speed printing processes. The observations made are consistent with the findings of Ifijen et al. (2022), who found that alkyd resins offer good pigment wetting and formulation flexibility but have lower mechanical durability than polyurethane and epoxy systems. However, their relatively low production cost and convenience of processing still suit the conventional commercial printing applications, which don't require extremely high durability.

The adhesion and rub resistance of all the formulations investigated were the highest in the case of polyurethane resin, which showed superior mechanical performance. These properties are a result of the extremely flexible polymer network being formed during the curing process, which leads to greater resistance to abrasion, scratches, and repeated mechanical deformations. The good water and chemical resistance exhibited by urethane inks also makes them ideal for packaging, labels and industrial printing inks where printed surfaces are subject to moisture, friction and chemicals. The results obtained are consistent with those reported by Ifijen et al. (2022), where polyurethane resins were found to be among the most resilient binder systems employed in today's coating and printing technologies.

Epoxy resin also showed excellent adhesion, chemical resistance and water resistance, with the highest chemical resistance values of all the resin systems studied. Epoxy resin's superior performance can be explained by its highly cross-linked molecular structure that can form densified polymer networks, which would prevent the penetration of solvents and environmental degradation. The formulation also had the highest viscosity and longest drying time, suggesting that although epoxy-based inks offer great durability, they might take longer to dry to optimum performance. A similar observation by Duan et al. (2017) was that the epoxy-modified acrylic binders significantly enhanced the adhesion and water resistance, but resulted in longer curing times.

One-way ANOVA showed that the differences between the four resin systems were statistically significant for each of the performance parameters measured and that Tukey HSD testing revealed that there were no significant differences between the two competing resin systems, polyurethane and epoxy, in the durability-related properties measured except where otherwise stated. Interestingly, the post hoc analysis did not show a significant overall difference between the polyurethane and epoxy formulations, indicating that the two

formulations have similar high-performance characteristics despite their different drying behaviour and viscosity. The result provides practical guidance to resin selection, as it is possible to choose the resin based on the production requirements, substrate compatibility, processing conditions and cost, and not on the assumption that one resin is better than the others.

The results can be summarised as follows: Overall, the results showed that there is no resin with all the qualities that can be used in all printing applications. Where high gloss, colour quality and fast drying are needed, acrylic resin is most suitable. Use of polyurethane resin is recommended in those applications that require very good flexibility, adhesion and resistance to abrasion, such as flexible packaging. Epoxy resin is suitable for industrial and speciality printing that demands high chemical and water resistance, while alkyd resin is a cost-effective material for traditional printing processes that have moderate durability demands. The findings are important scientific data for the optimisation of resin selection for the formulation of printing ink and are useful for continuous development of high-performance and sustainable printing technologies.

## VI. CONCLUSION AND RECOMMENDATIONS

This research examined the effect of various resin types on the performance of printing inks by comparing the performance of inks formulated using acrylic, alkyd, polyurethane and epoxy resins. The results showed that the type of resin has a significant effect on the rheological, optical, mechanical and chemical properties of the printing inks, such as viscosity, drying time, gloss, adhesion, colour density, rub resistance, water resistance and chemical resistance. These differences were statistically significant, which revealed that resin selection is an important factor in determining printed product quality and durability. In terms of optical performance, acrylic resin yielded the highest gloss, good colour density and the quickest drying time, which proved highly suitable for commercial printing applications where speed of production and good colour quality were of paramount importance. Polyurethane resin exhibited excellent adhesion and abrasion resistance, and epoxy resin exhibited exceptional water and chemical resistance, making it suitable for industrial and speciality printing applications that require high durability. Alkyd resin, on the other hand, gave good overall performance but had relatively poor durability and slower drying properties. From this study, it is recommended that the resin system used in printing inks should only be used for specific applications based on its properties rather than a single system for all applications. For high-speed printing, acrylic resins are recommended; for flexible packaging, polyurethane resins; and for chemically demanding environments, epoxy resins are recommended. Additionally, future studies on the printing performance of hybrid resin formulations, bio-based resins and waterborne ink systems should be explored to improve the performance of the print while minimising environmental impacts of VOC emissions. These investigations will help improve sustainable, cost-effective and high-performance printing ink technologies.

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