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SARL PIGMA
COLOR

Department of Process Engineering:

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Final Year Project Report

Formulation and characterization of Fluorescent Signaling Paint

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Dedication

***To myself first**, To the one who endured, struggled, and never gave up,*

I dedicate this work:

***To my beloved family**, My support in every step and my source of strength, to you, all my love and gratitude.*

*And to our brothers and sisters **in Palestine**, to the pure souls of the martyrs,*

To those who taught us the meaning of patience and resilience,

We dedicate this work as a gesture of solidarity, Praying that God grants them victory and peace.

Dedication

I dedicate this work first to myself, in appreciation of the effort made and the continuous pursuit of knowledge.

*To **my dear parents**, who have been a role model and a source of support throughout my academic and professional journey.*

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*And finally, to our brothers and sisters **in Gaza**, a symbol of resilience and determination, who constantly remind us of the value of steadfastness and human dignity .*

الملخص:

تهدف هذه الدراسة إلى تحضير وتوصيف طلاء إشارات مرورية قائم على الفلورية لتحسين الرؤية والسلامة الطرقية. تم تحضير تركيبات باستعمال أصباغ فلورية بألوان البرتقالي والأصفر والأخضر، وراتنج الأكريليك، ومذيب الزيلين، وإضافات خاصة. أظهرت الاختبارات استقرارًا لونيًا جيدًا تحت الأشعة فوق البنفسجية، ومقاومة جيدة للماء، مع مقاومة متوسطة للاحتكاك. بيّنت النتائج أهمية نسبة الصباغ في تحسين الخصائص البصرية للطلاء، مما يشجع على مواصلة تطويره لتطبيقات الإشارات المرورية.

Résumé:

Cette étude porte sur la formulation et la caractérisation d'une peinture de signalisation routière à base de fluorescence afin d'améliorer la visibilité et la sécurité routière. Des formulations contenant des pigments fluorescents orange, jaune et vert, une résine acrylique, du xylène et des additifs ont été préparées. Les essais ont révélé une bonne stabilité de la couleur sous rayonnement UV, une bonne résistance à l'eau et une résistance modérée à l'abrasion. Les résultats soulignent l'importance de la concentration en pigments dans les propriétés optiques du revêtement et son potentiel pour la signalisation routière.

Abstract:

This study focuses on the formulation and characterization of fluorescent road-signaling paint to improve visibility and road safety. Formulations containing orange, yellow, and green fluorescent pigments, acrylic resin, xylene, and specific additives were prepared. The tests showed good color stability under UV exposure, good water resistance, and moderate abrasion resistance. The results highlight the importance of pigment concentration in the coating's optical properties and its potential for road-signaling applications.

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List of Abbreviations

AISI : American Iron and Steel Institute

$BaSO_4$: Barium Sulfate

C* : Chroma

CR : Chromatic Reflectance

EVA : Ethylene Vinyl Acetate

HALS : Hindered Amine Light Stabilizers

h° : Hue Angle

L* : Lightness

LED : Light Emitting Diode

rpm : Revolutions Per Minute

S_0 : Ground Singlet State

S_1 / S_2 : Excited Singlet States

UV : Ultraviolet

VOC : Volatile Organic Compound

µm : Micrometer

Introduction :

The field of paints and technical coatings is considered one of the vital sectors that directly contributes to supporting industrial development and enhancing safety in various public facilities. The rapid development of infrastructure and road networks requires innovative solutions that ensure clear visibility and the continuity of their effectiveness under different climatic and temporal conditions especially during nighttime when the rate of traffic accidents increases due to poor visibility.

Despite the widespread use of traditional paints for road markings they remain limited in effectiveness in the absence of sufficient lighting. Moreover, their reflective intensity decreases over time due to friction and environmental factors. In addition, continuous reliance on public lighting increases energy consumption and maintenance costs, which encourages the search for more efficient and sustainable alternatives.

In this context, fluorescent coatings enhanced with reflective materials offer a promising solution for improving road marking visibility. Fluorescent pigments absorb ultraviolet or visible light and re-emit it instantly as brighter light, giving the coating high brightness and clarity during the day and in low-light conditions. The integration of these pigments within a suitable resin matrix results in a coating with good optical properties and mechanical resistance suitable for road applications.

The addition of reflective glass particles further enhances reflectivity, as these particles reflect headlights towards the driver, improving nighttime visibility and increasing road safety. Thus, this type of coating combines the daytime clarity of fluorescence with the enhanced nighttime visibility of reflective glass, making it suitable for modern road signage applications..

As part of the graduation project preparation, a field internship was conducted within Pigma with the aim of designing and studying the formulation of a luminous paint intended for traffic signs. The study focused on developing a formulation that achieves a balance between glow intensity and duration, application feasibility, and paint adhesion to asphalt or concrete surfaces, while evaluating its resistance to abrasion and various climatic conditions. This study also aimed to test the hypothesis that it is possible to reduce the need for artificial lighting by improving the fluorescent performance of the paint, thereby contributing simultaneously to improving road safety and reducing energy consumption.

This project consists of two main parts: a theoretical part and a practical part. The theoretical part presents a general overview of the host institution and fundamental concepts related to paints fluorescent materials , the mechanism of glow as well as applications of luminous coatings in the field of road signage.

The practical part includes the presentation of the materials and equipment used in the preparation and testing methodology followed by the presentation and discussion of the obtained results in light of the adopted technical standards leading to general conclusions regarding the effectiveness of the developed coating and future improvement prospects.

Chapter I :

Theoretical Part

Ⅰ.1.Company presentation [1]

I.1.1.Geographic location

The company covers an area of 6542 m^2 in the industrial zone of Sidi Khaled Oued El Bardi , Bouira



Figure 1 : Sarl Pigma Color Location

I.1.2.Organization of the company's workshops

- **General Administration** : (General management and administration , marketing and sales department , research and development department , purchasing and procurement department , finance and accounting department , human resources department , and health , safety and environment department)
- **A raw materials Storage Workshop**
- **A production workshop :** Paint manufacturing and packaging
- **A laboratory :** for quality control of finished products and raw materials and for the developments of new products
- **A finished goods storage workshop:** This warehouse also serves as a shipping platform for delivery to distributors across the entire national territory.

I.1.3.Company Organizational Chart :

PIGMA COLOR company has six departments at the same hierarchical level.

It has adopted a functional structure , where the main functions are all positioned at the same level and directly report to the General Management .

I.2.General Background

In modern transportation systems road markings serve not only to guide direct but are also critical for ensuring driving safety particularly in vital areas such as highways and airports , the rapid development of highway mileage and the aviation industry have imposed higher demands on the visual clarity and durability of road marking. Currently road marking are categorized into four types based on the paint used : thermoplastic , water-based , two-component , and solvent-based . Among this thermoplastic markings are mainstream[2].

I.2.1.Road Signage

Poor road marking visibility has had a negative impact on driving worldwide. To address this problem, numerous options have been employed, including but not limited to: improved lighting, the use of glass and acrylic beads, increased paint line area, LED lights, raised reflective markings, and luminescent paint. No single solution is perfect; each option has its own advantages and disadvantages.

Fluorescence refers to the phenomenon of light emission, usually with a wavelength slightly longer than the light initially absorbed. This process occurs on a timescale ranging from nanoseconds to microseconds. Thermoplastic coatings containing fluorescent materials have been studied for use on roads and found to improve visibility only when ultraviolet (UV) headlights are used. This is because UV light often contains the minimum energy per photon required to excite a charge carrier from the ground state to an excited state. In a material composed of a few atoms, there are energy levels for the ground and excited states, filled either with holes (electronic spaces with an effective positive charge) or electrons. A solid contains countless energy levels in both the excited and ground states, which form what are known as bands. A charge carrier first moves to a lower energy level within the excited band by releasing energy through vibrations within the material, and then

emits light at lower energies as it transitions from the excited band to the ground state band. Fluorescent materials have been widely used in road signs, and have been shown to have a positive effect on drivers compared to non-fluorescent orange signs[8].



Figure 2: Luminescent Road Signaling

I.2.2.Types of horizontal road markings

Horizontal road markings serve as critical safety tools by defining lane boundaries, guiding traffic flow, and providing essential information to drivers. These markings include reflective lane lines, stop lines, pedestrian crossings, and directional arrows, all of which work together to regulate vehicle movement at intersections and along highways. To ensure maximum safety, these markings are formulated with reflective materials that remain highly visible under headlights at night or during poor weather conditions. Furthermore, photoluminescent pigments are increasingly utilized to absorb ambient light and re-emit it in low-light zones, highlighting potential hazards and warning areas effectively without external energy[7].

I.2.3.Standard requirements

- **Visibility**

Daytime visibility is achieved through visual contrast between road marking and pavement. Nighttime visibility is reached by using glass microbeads embedded in the paint surface, so the drivers can receive a proper amount of reflected light, providing them an adequate road visibility at night and increasing their safety . The correct retroreflection value is attained through the combination of good quality microbeads and base material (white painting) in a correct dosage. Microbeads efficiency must be assessed for their different compositions and densities in the

painting embedment . Previous studies show that microbeads must be embedded from 1/3 to 2/3 of their diameter to optimise light retroreflection .

- **Durability**

Photoluminescent coatings were designed by dispersing photoluminescent pigments in a silicone epoxy hybrid binder hardened with a bifunctional silane which possesses a reactive primary amino and hydrolysable ethoxysilyl groups. The resulting emulsions were deposited by an automatic drawdown applicator on AISI 304 stainless steel flat substrates and allowed to dry at ambient conditions. The visual appearance of the coatings was analyzed by combined contact gauge profilometry and field emission gun scanning electron microscopy. Mechanical and tribological properties of the coatings were analyzed by scratch and linear reciprocating ball-on-flat sliding wear tests. Photoluminescence was characterized by capturing high resolution images of the surface with a digital camera and monitoring the decay of the intensity of the emitted photoluminescent radiations. High adherent and high durablility [13] .

- **Luminance and brightness**

Are among the most important optical properties of pavement markings because they directly influence drivers' visibility and guidance during night-time driving and under low-light conditions. Conventional road markings generally rely on retroreflective glass beads to reflect vehicle headlights, while recent developments have focused on fluorescent materials capable of emitting stored light over extended periods. These advanced materials can improve visual guidance on unlit roads and enhance traffic safety by increasing the visibility of lane boundaries and road directions.

The optical performance of luminous pavement markings depends on several parameters, including pigment characteristics, coating composition, particle size, and layer thickness. In addition to high luminance and long-lasting brightness, pavement-marking coatings must also exhibit adequate durability and resistance to environmental conditions such as moisture, abrasion, and chemical exposure to ensure long-term service performance [9].

I.2.4.Properties required in a road marking paint

The main properties required for road marking paint are:

- Fast drying.
- Easy application.
- Excellent adhesion.
- Very tough and abrasion resistant.
- Excellent UV resistance
- Excellent weather durability.
- Very low maintenance/repair costs
- Resistant to petrol, diesel, engine oil, water etc[10].

I.25.Fluorescent mechanism

Fluorescence is a type of photoluminescence, described as the temporary absorption of light energy by a substance followed by the immediate re-emission of that energy as light. The energy source is typically photons from ultraviolet or visible light. The capability of certain molecules to instantaneously convert absorbed high-energy light into lower-energy visible light makes fluorescence a widely used tool, forming the basis of many modern scientific and technological applications.

For fluorescence to occur, a material must be exposed to an external energy source, commonly ultraviolet or blue light, which is absorbed by the fluorescent substance. The most striking characteristic is the shift in color: the light emitted is always of a longer wavelength and lower energy than the light initially absorbed. For example, a molecule might absorb invisible ultraviolet light but then emit visible green light.

This predictable difference in energy between the excitation and emission wavelengths is known as the Stokes Shift. This shift allows scientists to use optical filters to easily separate the excitation light from the weaker emitted fluorescent light, making the phenomenon highly measurable. The emission speed is also defining; the glow ceases almost instantaneously, typically within billionths of a second, once the external light source is removed.

The process begins when a molecule, initially in a stable, low-energy ground state (S0), absorbs a photon of energy. This absorbed energy instantaneously promotes one of the molecule's electrons to a higher-energy, unstable excited singlet state (S1 or S2). The electron maintains the same spin orientation it had in the ground state, which is characteristic of the singlet state.

The excited electron immediately begins to lose some excess energy through a rapid, non-radiative process called vibrational relaxation. During this relaxation, which occurs within picoseconds (10^{-12} seconds), the electron drops down to the lowest vibrational level of the first excited singlet state (S1). This energy is often dissipated as heat or infrared radiation into the surrounding environment.

Fluorescence emission is the final step, occurring when the electron transitions directly from the lowest excited singlet state (S1) back down to the ground state (S0). This return releases the remaining energy as a single photon of light. Because a portion of the initial energy was lost during vibrational relaxation, the emitted photon carries less energy, resulting in the longer wavelength light observed in the Stokes Shift. The entire cycle is extremely fast, with the excited state lifetime averaging only a few nanoseconds (10^{-9} seconds) [12].

I.2.6.Factors influencing the duration and intensity of emission

- **Binder**

With the same binder considered, various factors can influence the trend of the emission spectrum, which is, moreover, quite similar for the two types of binders examined. Among these factors are:

The presence of other components in the preparation of a specific binder, as exemplified in particular by the differences between the spectra obtained for tempera prepared with or without the addition of vinegar as a preservative.

The partial reabsorption of the radiation emitted by the pigments mixed with the binder, which can cause a shift in the emission maximum or make it difficult to observe the fluorescence band; this effect can be at least partially corrected with an appropriate mathematical procedure; The overlapping of the emission due to the binder and that of the pigment/lake dispersed in it [14].

- **Temperature and solvent**

A molecule's fluorescent quantum yield also is influenced by external variables, such as temperature and solvent. Increasing the temperature generally decreases , because more frequent collisions between the molecule and the solvent increases external conversion. A decrease in the solvent's viscosity decreases for similar reasons. For an analyte with acidic or basic functional groups, a change in pH may change the analyte's structure and its fluorescent properties[15].

- **Thickness**

The thickness of the fluorescent paint film plays a determining role in the intensity of the emitted fluorescence. In general, an increase in the applied coating thickness leads to an increase in fluorescence intensity, since a larger amount of fluorescent pigments is present and capable of absorbing the incident radiation and re-emitting it as visible light. However, this increase is not unlimited; beyond a certain critical thickness, the fluorescence intensity may stabilize or even decrease. This phenomenon is mainly attributed to self-absorption and light scattering within the film, which reduce the efficient transmission of both the excitation radiation and the emitted light. Furthermore, the film thickness also affects other optical properties such as gloss, opacity, and transparency of the coating. Therefore, optimizing the film thickness represents an essential parameter in the formulation of fluorescent paints in order to achieve maximum visibility and optical performances suitable for signaling applications[16].

- **Optical Behaviour, Transparency and Substrate Influence of Daylight Fluorescent Pigments**

The colors of daylight fluorescent pigments are very saturated. Saturated means vivid, bright or strong when it describes color. A daylight fluorescent pigment has its own color. In other words, a daylight fluorescent pigment reflects light at certain wavelengths selectively. So it has a color even when it is not emitting fluorescence.

Besides, daylight fluorescent pigments appear to be unusually bright in daylight or under household fluorescent fixtures compared to non-fluorescent pigments. Some daylight fluorescent pigments glow. What happens to daylight fluorescent pigments is that the pigment's own color

(reflected color) and the color of the pigment's fluorescence are similar. On the reflectance spectrum, the maximum reflectance and the dominant peak of the fluorescence appear in the same wavelength region. Thus, the light reflected on the surface of the pigment and the light emitted (as fluorescence) combine to form a higher peak on the reflectance curve. As a result, an extremely intense color is perceived.

Moreover, another unique property of daylight fluorescent pigment is transparency. They lack opacity; in other words, they have less hiding power compared to most non-fluorescent pigments due to the clear materials that are used as the solid carrier of these fluorescent pigments.

When a daylight fluorescent pigment on a painting is illuminated, a portion of the light passes through the pigmented layer, is reflected by the substrate, and comes back through the paint layer and unites with the light that comes from the paint surface. Therefore, the unusually bright appearance of a daylight fluorescent pigment is due to the combined effect of the light reflected on the pigment surface, its fluorescence and the light reflected by the substrate. A daylight fluorescent pigment appears purer and brighter when it is painted on a white surface rather than on a dark colored surface. It is true, though, that non-fluorescent pigments, especially lake pigments precipitated on barium sulphate ($BaSO_4$), also transmit light to some extent [17].



Figure 3: fluorescent pigment

I.2.7.Definition of paint

According to the Technical Dictionary of Paints, paint is a liquid paste-like , or powder product containing pigments intended to be applied to a surface in order to from an opaque layer with protective or decorative properties with the aim of protecting improving the surface. it enhances the appearance of various surfaces such as walls , ceiling , floors and furniture[3].

, 

Figure 4: Industrial fluorescent Paint

I.2.8.Composition of paint

Organic coatings are complex mixtures of chemical substances that can be grouped into four broad categories: (1)binders, (2) volatile components, (3) pigments, and (4)additives.

I.2.8.1.Binders

Are the materials that form the continuous film that adheres to the substrate (the surface being coated),bind together the other substances in the coating to form a film, and present an adequately hard outer surface. The binders of coatings within the scope of this book are organic polymers some made via synthetic organic chemistry and some derived from plant oils.In some cases, these polymers are prepared and incorporated into the coating before application; in other cases, lower molecular weight organic materials (monomers or oligomers) are mixed with the other components of the coating, and final polymerization takes place after the coating has been applied. Binder polymers and their precursors are often called resins. The binder governs, to a large extent, the properties of the coating film[4].

I.2.8.2.Volatile components

Are included in a large majority of coatings and are often referred to as solvents. They play a major role in the synthesis, mixing, and application of coatings. They are liquids that make the coating fluid enough for application, and they evaporate during and after application Because of the need to reduce the environmental impact of coating manufacture and application, a major continuing drive in the coatings field is to reduce the use of volatile organic compounds (VOCs) by making the coatings more highly concentrated (higher solids coatings), by using water as a

major part of the volatile components (water borne coatings), and by eliminating solvents altogether.

Solvents are classified into three categories:

- Light solvents: boiling point below 100°C.
- Medium solvents: boiling point below 130°C.
- Heavy solvents: boiling point above 130°C.

I.2.8.3.Pigments

Are finely divided, insoluble solid particles, ranging from a few tens of nanometers to a few hundred microns in size, that are dispersed in the vehicle and remain suspended in the binder after film formation. Generally, the primary purpose of pigments is to provide color and opacity to the coating film. Additionally, pigments can provide other functions, such as corrosion-inhibiting pigments, which enhance the corrosion protecting properties of the coatings. Pigments also play a major role in the application characteristics and the mechanical behavior of coatings [4].

I.2.8.4.Fillers

Fillers are also powdery products insoluble in the dispersion medium, but have negligible opacifying power, generally mineral powders. They have neither covering nor coloring power, their refractive index being close to that of the binders. These substances include calcium carbonate ($CaCO_3$), barium sulfate ($BaSO_4$), silicas, pumice, etc.

Fillers play an important role in the rheological characteristics of a paint (viscosity, flow, etc.), its impermeability, ease of sanding, and resistance to abrasion. For example, it can reduce gloss, increase the mechanical properties of the film (which also allows for the even distribution of pigments). This is the role of magnesium silicate. It can also reduce production costs through the use of calcium carbonate, for example[5].

I.2.8.5.Additives

In addition to the main components of a paint : binders, pigments, and solvents, a series of various additives are added in varying proportions. These are complementary chemical elements with

specific functions and properties, even when present in small amounts in the paint's composition. Their roles are very varied: facilitating manufacturing, storage, and application, or giving the paint special anti-corrosive, fungicidal, or insecticidal properties: any insects are eliminated when they come into contact with the painted wall. There are also anti-mite paints recommended for sensitive or asthmatic individuals.

- **Thickening agent**: used to increase the viscosity of paints and prevent drips or delay the settling of powdery materials
- **Dispersive agent:** this is an agent that
  - helps the machine disperse products (energy saving).
  - eliminates coagulation and makes the paint more durable.
  - maintains viscosity over time

These last two additives are found in water-based paints as well as in solvent-based paints. For water-based paints, other additives are added such as:

- **Coalescing agent:** this is an agent that facilitates film formation at low temperatures.
- **Anti-foaming agent**: prevents foam formation during manufacturing.
- **Preservative:** prevents bacterial growth.

And for solvent-based paints, we add:

- **drying agent:** a mixture of metals that accelerates drying
- **anti-skinning agent:** delays the formation of a skin [5].

I.2.9.Types of Paints[5]

- **Water-Based Paints**

The term "water-based" refers to paints that are diluted with water. They are also called "water-based paints" Several types exist, such as:

- **Solvent-based paint**

The term "solvent-based" refers to paints that are diluted with an organic solvent (here, "organic" does not mean "biological" or "natural"). Examples include:

- **Glycerophthalic paint**

As its name suggests, this paint contains a glycerophthalic resin; it dries by oxidation of its binder and by evaporation of the organic solvents it contains.

I.2.10.Paint Manufacturing Process[5]

Our goal is to obtain a homogeneous mixture, visible to the naked eye, and to maximize the coloring strength of the pigments. The use of a wetting agent is often necessary to improve and facilitate the incorporation (introduction) of pigments into the liquid phase. The additive also reduces the surface tension of the liquid and thus increases its wetting capacity. This can be achieved by reducing the size of the aggregates and agglomerates to an optimal particle size, through the use of appropriate additives for good wetting and dispersion (high shear rate 1000-2500 rpm). The procedure followed is as follows:

1) **Mixing (wetting):** During which the solid elements (pigments and fillers) are dispersed in a portion of the binder, solvents, and additives .
2) **Grinding and dispersion:** The shear forces developed in this phase must be greater than the cohesive forces that bind the particles together in order to deagglomerate the pigments and fillers, achieve a uniform mixture, and obtain the maximum desired film fineness .
3) **Finishing and adjustment:** During this step, the additives are evenly distributed throughout the paste, meaning sufficient mixing time is required to prevent particle re-agglomeration. Thus, the formula grinding is completed, the tint is adjusted, and the paint achieves the desired characteristics
4) **Filtration**: Filtration is carried out to remove impurities and to trap small particles using the grinding media (glass beads, zirconium beads, ceramic beads). Paints can be filtered in a variety of ways, and the end use of the product determines the type of filtration. The use of 40 to 80 µm filters is recommended for filtering paints and finishing lacquers
5) **Packaging:** Fill the paint into cans or drums, which will then be palletized.
6) **Storage:** Store in sheltered storage buildings at ambient temperature.

7) The following diagram summarizes the steps in the paint manufacturing process:

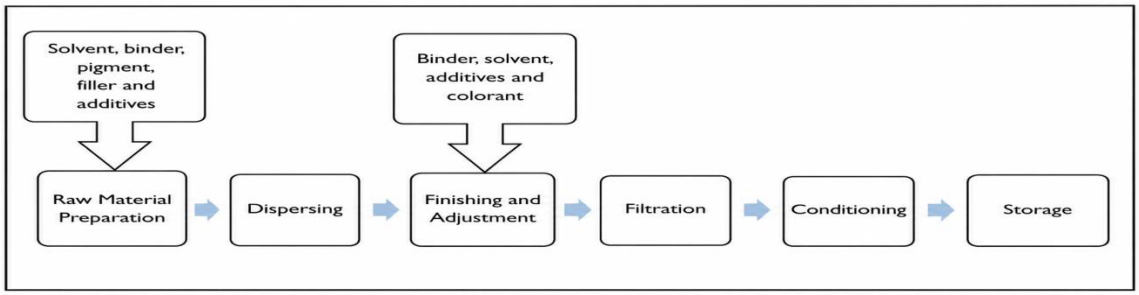


Figure : *Paints manufacturing process*

I.2.11.Interaction between fluorescent pigment and binder:

The interaction between fluorescent pigments and the binder plays a crucial role in determining the final optical and mechanical properties of the coating. Fluorescent pigments, being finely divided solid particles, are dispersed within the binder system where they must remain uniformly distributed to ensure consistent color intensity and brightness. The binder acts as a continuous phase that immobilizes the pigment particles after film formation and strongly influences their optical behavior by affecting light absorption, scattering, and emission. Good compatibility and prevents sedimentation. Conversely, poor interaction can lead to pigment flocculation, reduced fluorescence efficiency, and uneven color development.

To improve this interaction, several strategies can be applied. Surface modification of fluorescent pigments using coupling agents or functional coatings can increase their affinity toward the binder. The use of compatibilizers or dispersing additives helps to stabilize the pigment within the resin matrix and prevents agglomeration. Proper selection of the binder chemistry, ensuring polarity matching with the pigment surface, also enhances interfacial adhesion. In addition, optimizing processing conditions such as mixing time, shear rate, and dispersion energy contributes to a more homogeneous distribution and stronger pigment–binder interaction. Overall, improving interfacial compatibility is essential for achieving high-performance coatings with stable and vivid fluorescent effects[19].

I.2.12.Specific constraint

I.2.12.1.UV stability

The improvement of coating performance against ultraviolet (UV) radiation strongly depends on the incorporation of specific stabilizing systems. Among the most important are UV stabilizers such as hindered amine light stabilizers (HALS), which act by trapping free radicals formed during UV-induced degradation processes. This mechanism interrupts chain reactions in the polymer matrix and prevents bond cleavage, thereby slowing down material degradation.

UV absorbers are another important class of additives. These compounds absorb harmful UV radiation and dissipate the absorbed energy as heat, preventing it from reaching and damaging the polymer backbone. Common chemical structures used for UV protection include hydroxyphenylbenzotriazoles, hydroxyphenyltriazines, benzophenones, and hindered amine compounds (HALS), all of which are widely used in industrial coating formulations.

- **Polymer selection**

The selection of the binder or polymer plays a fundamental role in determining the resistance of coatings to UV radiation and weathering conditions. For exterior applications, several types of polymers are commonly used, including acrylic and polyester resins. These materials are widely preferred due to their excellent durability, strong resistance to UV degradation, and good weathering stability under outdoor exposure conditions.

- **Pigment selection**

The choice of pigments significantly influences the UV stability and long-term durability of coatings. Inorganic pigments are generally preferred for exterior applications due to their high resistance to photodegradation and weathering. These pigments help maintain color stability and reduce the deterioration of the coating under prolonged UV exposure[20].

I.2.12.2.Abrasion

Under severe environmental conditions such as strong UV radiation and heavy rainfall, traditional pavement marking materials often suffer from reduced durability and poor resistance to wear. To

overcome this limitation, the incorporation of ethylene–vinyl acetate (EVA) copolymer into petroleum resin-based formulations has been shown to significantly improve abrasion resistance.

In addition, optimizing the proportions of resins, pigments, fillers, and plasticizers using mixture design techniques enhances the mechanical performance and anti-pollution properties of pavement markings. The addition of glass microbeads also plays a crucial role by improving reflectivity and visibility, which contributes to both safety and durability[21].

I.2.12..3.Humidity

Thermoset acrylic–melamine coatings are widely used for exterior applications due to their good initial performance. These coatings are typically formed by reacting acrylic polyols with alkylated melamine-formaldehyde resins. However, their performance can be affected by environmental conditions such as humidity, UV radiation, and temperature.

In humid environments, these coatings may undergo hydrolysis, leading to the breakdown of ether crosslinks and the formation of melamine–melamine linkages. The degradation rate depends on factors such as temperature, acidity, and the type of melamine resin used. Studies have shown that UV radiation can significantly accelerate hydrolysis, making degradation faster than the combined effects of UV and moisture acting separately.

Overall, the combined exposure to UV light, oxygen, and moisture results in complex degradation mechanisms, where the rate of deterioration increases with relative humidity and environmental severit [22].

Chapter II :

Experimental Part

II.1 methods and materials

This section aims to prepare and study a traffic sign paint based on fluorescence, which allows the paint to become visible when a light source is shone upon it, especially at night. This work involved selecting suitable materials, including fluorescent pigments, binders, and solvents, and then preparing and applying several formulations to different surfaces. Tests were also conducted to evaluate the paint's properties, such as luminescence intensity, drying speed, and adhesion, in order to obtain an effective paint that meets safety and usage requirements.

II.1.1.Raw Materials

II.1.1.1.Fluorescent pigments

Fluorescent pigments used in this study include three different colors: orange, green, and yellow. These pigments were selected due to their high visibility and strong emission under external light sources, making them suitable for road marking applications. The variation in colors allows better visual perception under different lighting conditions, especially at night when illuminated by vehicle headlights.

II.1.1.2.Binder (Acrylic)

In this study, acrylic resin was used as the binder in the preparation of the paint. This type of resin is characterized by good adhesion to various substrates, as well as resistance to environmental factors such as moisture and abrasion. It also contributes to improving the cohesion of the paint components and ensuring the stability of the fluorescent pigments, leading to a coating with good performance and durability.

II.1.1.3.Solvent (xylene)

In this study, xylene was used as the solvent in the paint formulation. Xylene is an aromatic organic solvent characterized by good solvency power for resins and coating materials. It helps in adjusting the viscosity of the paint, facilitating its application on different substrates. Due to its relatively slow evaporation rate, xylene also contributes to improving the leveling and film formation of the coating.

II.1.1.4.Additives

In this study, two types of additives were used in the paint formulation:

- **An anti-UV additive :** The anti-UV additive was included to improve the paint's resistance to ultraviolet radiation, thereby increasing its durability and preventing deterioration over time.
- **The dispersing agent** : was used to ensure a uniform distribution of the fluorescent pigments within the resin, preventing clumping and improving the overall uniformity of the paint.

II.1.1.5.The substrate

Applying the paint to a white/black contrast card-type substrate, which is widely used in laboratory tests for paints, is done to evaluate the coating's coverage and uniformity on different surfaces, as well as to study its light intensity and fluorescence properties when exposed to a light source. This allows for an accurate perception of the paint's performance in terms of visual clarity and efficiency under different lighting conditions, especially in safety and traffic signal applications.

The composition for both experiments was as follows:

Table 1: Composition of paint formulation experiment 1

Materials	Green	Orange	Yellow
Binder (Acrylic)	***434g (62%)***	***420g (60%)***	***406g (58%)***
Solvent (Xylene)	***73.5g (10.5%)***	***87.5g (12.5%)***	***101.5g (14.5%)***
Dispersing agent	***3.5g (0.5%)***	***3.5g (0.5%)***	***3.5g (0.5%)***
Fluorescent pigment	***175g (25%)***	***175g (25%)***	***175g (25%)***
Additive (anti-UV)	***14g (2%)***	***14g (2%)***	***14g (2%)***

Table 2: : Composition of paint formulation exp 2

Materials	Green	Orange	Yellow

Binder (Acrylic)	***360g (60%)***	***348g (58%)***	***336g (56%)***
Solvent (Xylene)	***57g (9.5%)***	***69g (11.5%)***	***81g (13.5%)***
Dispersing agent	***3.5g (0.5%)***	***3.5g (0.5%)***	***3.5g (0.5%)***
Fluorescent pigment	***168g (28%)***	***168g (28%)***	***168g (28%)***
Additive (anti-UV)	***14g (2%)***	***14g (2%)***	***14g (2%)***

II.1.2. Experimental formulation

In this study, several formulations were prepared by varying the proportions of some of the components listed in the table, particularly acrylic resin (bonding agent), solvent (xylene), dispersing agent, fluorescent pigment, and additives.

Each formulation represents a precisely defined mixture, where some components, such as the fluorescent pigment and certain additives, were fixed, while the proportions of others were varied.

For example, fluorescent pigment and certain additives serve as constant parameters to isolate and precisely analyze the effects of the other components without the simultaneous interference of multiple factors.

The components whose proportions were altered, such as resin, solvent, and dispersing agent, were modified because they play a crucial role in determining the system's properties, including pigment dispersion, viscosity, and stability, as well as optical properties like transparency and color intensity.

Changing these proportions allows for an independent understanding of each component's impact on the final coating performance. For example:

- Increasing the resin content may improve adhesion but could affect transparency.
- Increasing the solvent content reduces viscosity but may affect stability.
- The dispersing agent improves the pigment's uniform distribution within the medium.

Therefore, this carefully considered variation in proportions aims to identify the optimal formulation that achieves the best balance between the coating's physical and optical properties.

II.1.2.1.Dispersion Method

In this study, the dispersion method was adopted, preparing the formulation step-by-step with continuous stirring using a disperser. First, acrylic resin was added, followed by the solvent and dispersing agent. The mixture was then homogenized using a high-speed mixer to ensure thorough blending of the components.

Next, the fluorescent pigment was added gradually with continuous stirring to ensure even distribution and prevent clumping. Finally, an anti-UV agent was added to improve the coating's UV resistance and increase its durability

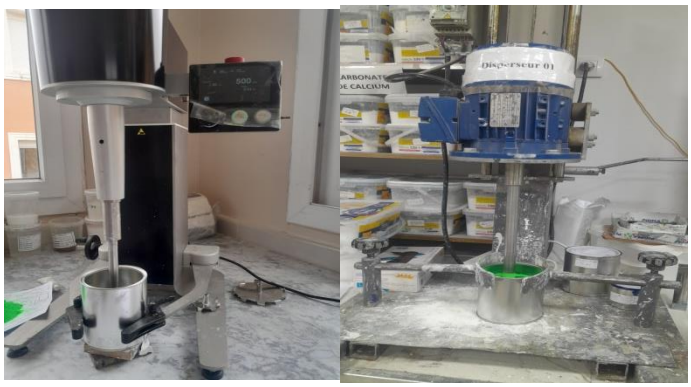


Figure 5: Disperser

II.1.2.2.Operating conditions

In this study, the operating conditions during the preparation of the formulations were carefully controlled to obtain accurate and comparable results across different samples.

The operating temperature was maintained at approximately 23°C, as temperature directly affects the resin viscosity and dispersion behavior. A significant increase in temperature could alter the mixture properties or degrade the pigment stability. Therefore, the temperature was kept constant to prevent any external influence on the results.

The mixing process was carried out using a high-speed disperser at a speed between 1800 and 2800 rpm. This speed is essential to ensure the breakdown of agglomerates and achieve a homogeneous distribution of the pigments within the resin medium. Selecting this speed range allows for good dispersion without damaging the particles or affecting the system's stability.

The mixing time was also limited to 15 minutes to avoid overheating caused by friction within the device, which could affect coating properties such as viscosity or the stability of the fluorescent pigment. Furthermore, continuous stirring was maintained during the addition of the various components, particularly the fluorescent pigment, to ensure its uniform distribution and prevent settling or clumping within the mixture. All samples were prepared under the same operating conditions to guarantee a fair and accurate comparison between the different formulations.

II.1.3.Application

II.1.3.1.Surface preparation

Before applying the paint, the substrate is carefully prepared to ensure good adhesion and a high-quality finish. First, the surface is cleaned to remove dust, impurities, and grease residues using a suitable method, thus preventing any obstacles that could affect the paint's bond with the substrate. Next, it is verified that the surface is completely dry and free of any moisture that could interfere with the application process.

In some cases, adhesion can be improved by slightly roughening the substrate surface, which enhances the mechanical bond between the paint and the surface. This step is particularly important when working with smooth surfaces.

Surface preparation is one of the most critical stages in paint application, as it directly affects the adhesion, uniformity, and durability of the final coat. This stage is especially important for thin-film coatings (approximately 120 micrometers), since any surface defect or contaminant can lead to poor coverage, unevenness, or even peeling of the paint after drying. Therefore, the same surface preparation procedures were adopted for all samples, in order to ensure uniformity of experimental conditions and to obtain accurate and comparable results.

II.1.3.2.Applied thickness

A coating thickness of approximately 120 micrometers (µm) was selected in this study as a suitable thickness for fluorescent traffic signal coatings. This selection was not arbitrary but rather based on the requirements of road coatings, which need to balance optical performance with mechanical properties.

Optically, this thickness allows the fluorescent properties of the pigments to be clearly displayed when exposed to ambient light, such as vehicle headlights at night, thus contributing to improved visibility and road safety. At the same time, this thickness is not excessively thick, which would compromise the uniformity of the coating or reduce its reflectivity.

Mechanically, a moderate thickness improves the coating's cohesion and reduces the likelihood of cracking or peeling during use, especially under weather conditions and heavy traffic. It also ensures a balance between abrasion resistance and ease of application to road surfaces.

II.1.3.3.Drying time

The drying time of fluorescent paint was studied to assess the speed of final layer formation, a crucial factor in road applications as it affects work completion speed and road opening to traffic. Proper drying time also ensures the fluorescent pigments are well-fixed within the layer and maintain their optical properties.

II.1.4.Characterization

II.1.4.1.Physical properties

- **Viscosity**

The viscosity of the prepared formulations was measured using a viscometer. During the measurement, module 4 was used as the instrument's constant setting, as using values lower or higher resulted in an error.

The rotation speed was adjusted between 10 and 20 rpm depending on the component ratios in each formulation, particularly when the solids content exceeded 46%. This higher percentage

increases the system's viscosity, thus requiring an appropriate speed for accurate and stable measurements.

Viscosity is a crucial characteristic in this work because it directly affects application ability, coating uniformity, and surface diffusion behavior. Therefore, the same measurement conditions were maintained for all samples to ensure the accuracy and comparability of the results.

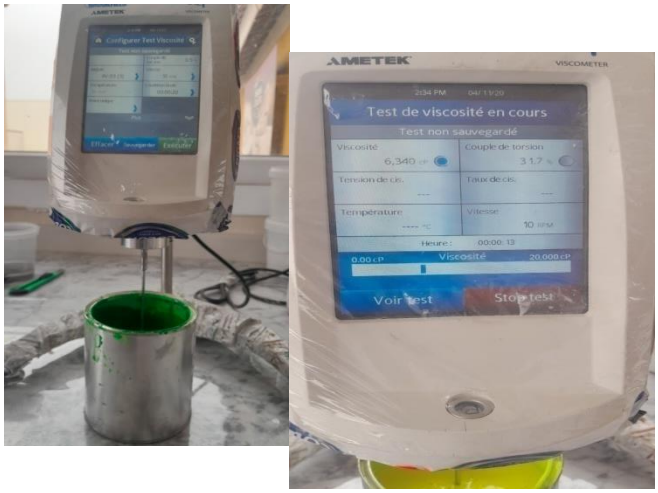


Figure 6: Viscometer

- **Density**

The density of the fluorescent coating was measured using a pycnometer to determine the bulk density of the formulation. This test is important in the field of fluorescent coatings because it reflects the concentration of components within the system and their impact on the coating's physical properties.

The measurement was performed using a constant volume of 100 mL. The pycnometer was filled with the sample and weighed accurately, yielding a mass of approximately 200 g. Based on these values,

This property helps assess the homogeneity of the formulation and monitor the distribution of components such as resin and fluorescent pigments. It also indirectly affects application

characteristics such as viscosity, layer thickness, and coating stability during use, particularly in traffic signal applications.



Figure 7 :Pycnometer

Chapter III :

Results and Discussions

III.1.Results of the quality control of the prepared paints

In this chapter, we will present the results obtained from the various analyses carried out during our internship, related to the design and quality evaluation of traffic sign coatings.

III.1.1.Adhesion

The adhesion properties of fluorescent paint layers were evaluated to determine the paint's bonding strength to the substrate and its ability to remain intact during use. This property is a crucial criterion in road coatings, as it directly impacts the coating's durability and resistance to external factors such as abrasion and traffic.

The adhesion test was conducted using a suitable method, such as the cross-cut test, where a light grid is applied to the paint surface and then adhesive tape is used to assess the layer's adherence to the surface after stretching. Good results indicate strong bonding between the paint and the substrate.

In the case of fluorescent paint, good adhesion is essential to ensure the layer's stability and the long-term effectiveness of its fluorescent optical properties, especially under road conditions and constant exposure to weathering.

III.1.2.Abrasion resistance

The abrasion resistance of the fluorescent coating was evaluated using a simple abrasion test under laboratory conditions, where the dry coating was subjected to repeated abrasion with a suitable medium. Slight abrasion was observed on the coating surface, manifested as a partial decrease in color intensity without complete peeling of the coating, indicating that the coating possesses moderate abrasion resistance under the studied conditions.

The following results were obtained from these experiments :

Table 3:Experimental results of paint characterization

Parameters	yellow pigment-based signaling	orange pigment-based signaling	Green pigment-based signaling
Viscosity 1(poise)	***60.80***	***75.87***	***101.6***
Viscosity 2 (poise)	***44.10***	***56.6***	***75.47***
Density 1	***1.0217***	***1.014***	***1.0353***
Density 2	***0.988***	***1.0058***	***1.0156***
Drying time 1(min)	***16***	***18***	***26***
Dryingtime 2(min)	***20***	***24***	***24***

III.1.3.Optical properties

- **Fluorescence duration**

Fluorescence duration represents the time a fluorescent coating retains its ability to emit light after exposure to an external light source. This property is important in traffic sign applications because it determines how long the sign remains visible after the direct light source is turned off.

Fluorescence duration was assessed by exposing samples to a constant light source for a specific duration, then monitoring the gradual decrease in light intensity under complete darkness, recording the time at which the light became very faint or invisible.

In this study, the results showed that fluorescent coatings retained their luminescence for approximately 5 to 15 minutes after the light source was turned off, depending on the sample composition and the percentage of fluorescent pigment used. It was also observed that some formulations with a higher pigment percentage exhibited a longer luminescence duration compared to other formulations.

III.1.4.Durability

- **Water resistance**

In this study, water resistance was evaluated by immersing the coated samples in room-temperature water for a specified period. After the test period, the samples were removed and allowed to air dry, and their condition was then observed.

It was noted that no change occurred in the coating's appearance; the layer remained intact, and no peeling, swelling, or discoloration was observed. This indicates that the coating possesses good water resistance and suitable stability under humid conditions.



Figure 8 : UV-spectroscopy



Figure 9 :Fluorescent paint (orange)

III.1.5.UV Resistance

III.1.5.1.Paint Orange:

This **table (04)** presents the main results of the quality control of the paint orange :

Table 4: Result of uv-spectroscopy of fluorescent paints orange.

	Signage using Orange fluorescent pigment	
	1st week results	
	Experiment 1	Experiment 2
L*	***74.89***	***72.25***
a*	***91.69***	***91.86***
b*	***84.94***	***79.97***
c*	***124.98***	***121.79***
h*	***42.81***	***41.04***
Color strength	***100***	***100***
	2nd week results	
	Experiment 1	Experiment 2
L*	***74.82***	***72.19***
a*	***90.16***	***90.56***
b*	***81.55***	***77.52***
c*	***121.57***	***119.21***
h*	***42.13***	***40.58***
Color strength	***100***	***100***

- For Orange 1, the comparison between week 1 and week 2 shows that the lightness value (L*) remained almost constant with a very slight decrease, indicating no significant change in brightness. The (a*) and (b*) values showed slight decreases, reflecting a minor reduction in the red and yellow components, and therefore a slight decrease in orange color intensity. The chroma (C*) also showed a small decrease between the two weeks, indicating a slight loss of color purity without affecting the overall appearance. The hue angle (h°) remained nearly stable, confirming that the orange color identity was preserved. In addition, the colorant force remained constant at 100, indicating that the pigment's tinting strength was not affected.
- For Orange 2, the results show a higher level of stability between week 1 and week 2. The lightness (L*) remained almost unchanged with a very slight decrease. The (a*) and (b*) values also showed only minimal variations, indicating a slight reduction in color intensity without a noticeable change in hue direction. The chroma (C*) showed a small decrease, reflecting a

slight reduction in color purity, while the hue angle (h°) remained stable, confirming that the orange tone was maintained. The colorant force also remained unchanged at 100.

- The results obtained for the samples over the first and second weeks, with an increase in fluorescent pigment content from 25% to 28% under UV exposure, show that all formulations maintained good overall color stability, with only minor variations in the color parameters and no significant degradation in optical performance.

III.1.5.2.Paint Yellow:

This **table (05)** presents the main results of the quality control of the paint yellow :

Table 5: : Result of uv-spectroscopy of fluorescent paints Yellow

	Signage using Yellow fluorescent pigment	
	1st week results	
	Experiment 1	Experiment 2
L*	***107.68***	***105.13***
a*	***-35.95***	***-31.23***
b*	***124.38***	***122.48***
c*	***129.47***	***126.39***
h*	***106.12***	***104.31***
Color strength	***100***	***100***
	2nd week results	
	Experiment 1	Experiment 2
L*	***107.4***	***104.64***
a*	***-38.45***	***-30.85***
b*	***122.71***	***121.68***
c*	***128.8***	***125.53***
h*	***107.4***	***104.23***
Color strength	***100***	***100***

- For Yellow 1, the comparison between week 1 and week 2 shows that the lightness value (L*→ Lightness) remained almost constant, indicating no significant change in brightness.\
  In contrast, the (a*→ Green–Red coordinate) value shifted slightly toward more negative values, indicating a slight tendency toward green, while the (b*→ Blue–Yellow coordinate) value showed a small decrease, reflecting a slight reduction in yellow intensity. A noticeable decrease in chroma (C*→ Chroma) was also observed between the two weeks, indicating a

partial loss of color purity. However, the colorant force remained constant at 100, confirming that the pigment's tinting ability was not affected.

- For Yellow 2, the comparison between week 1 and week 2 shows a much higher level of stability. The L* value remained nearly unchanged with only a slight decrease. The (a*) and (b*) values also showed minimal variations, indicating stable color direction. In addition, chroma (C*) remained almost constant, reflecting better preservation of color purity compared to yellow 1. The colorant force also remained unchanged at 100. Overall, the results indicate that both formulations exhibited good resistance to UV exposure and acceptable color stability, although yellow 2 showed better stability than Jaune 1 in terms of maintaining chroma and color purity.

III.1.5.3.Paint Green:

This **table (06)** presents the main results of the quality control of the paint green:

Table 6: : Result of uv-spectroscopy of fluorescent paints Green.

	Signage using Green fluorescent pigment	
	1st week results	
	Experiment 1	Experiment 2
L*	***70.43***	***65.65***
a*	***-88.11***	***-84.85***
b*	***60.52***	***54.63***
c*	***106.9***	***100.92***
h*	***145.52***	***147.23***
Color strength	***100***	***100***
	2nd week results	
	Experiment 1	Experiment 2
L*	***68.18***	***65.65***
a*	***-85.30***	***-85.60***
b*	***56.28***	***55.87***
c*	***102.19***	***102.22***
h*	***146.59***	***146.87***
Color strength	***100***	***100***

- For Green 1, the comparison between week 1 and week 2 shows that the lightness value (L*) remained almost stable with only a slight decrease, indicating no significant change in

brightness. The (a*) value remained very close to its initial level with minimal variation, showing no clear shift toward red or green, which reflects the stability of the green hue. The (b*) value showed a slight decrease, indicating a minor change in the yellow/blue component without affecting the overall appearance. The chroma (C*) slightly increased, suggesting a small improvement in color purity or visual stability. The hue angle (h° → Hue angle) remained nearly constant, confirming the preservation of the green color identity. In addition, the colorant force remained constant at 100, indicating that the pigment's tinting strength did not change.

- For Green 2, the results show even greater stability between week 1 and week 2. The lightness (L*) decreased slightly, indicating a minor darkening effect without any significant visual impact. The (a*) value remained almost unchanged, confirming a stable green direction, while the (b*) value showed only minimal variation, reflecting stable secondary color components. The chroma (C*) remained nearly constant, indicating good preservation
  of color purity, and the hue angle (h°) also remained stable, confirming no change in color tone. The colorant force also remained unchanged at 100.

III.1.6.Influence of pigment levels on brightness

The results show that increasing the pigment concentration from 25% to 28% resulted in a rise in luminosity, as confirmed by the higher L* value in the second sample.

This indicates that adding more pigment improved the paint's ability to reflect light rather than absorb it, resulting in a brighter color.

This can be explained by:

The pigment used has a high reflectivity (reflective pigment)

Or, increasing the concentration improved surface coverage (opacity), reducing the effect of the black background on the opacity chart and thus increasing the amount of light reflected towards the eye.

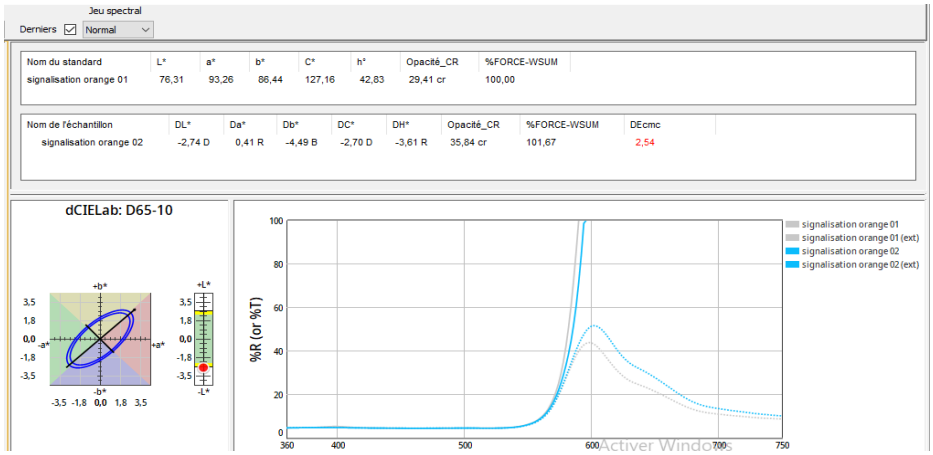


Figure 10 :orange pigment-based signaling

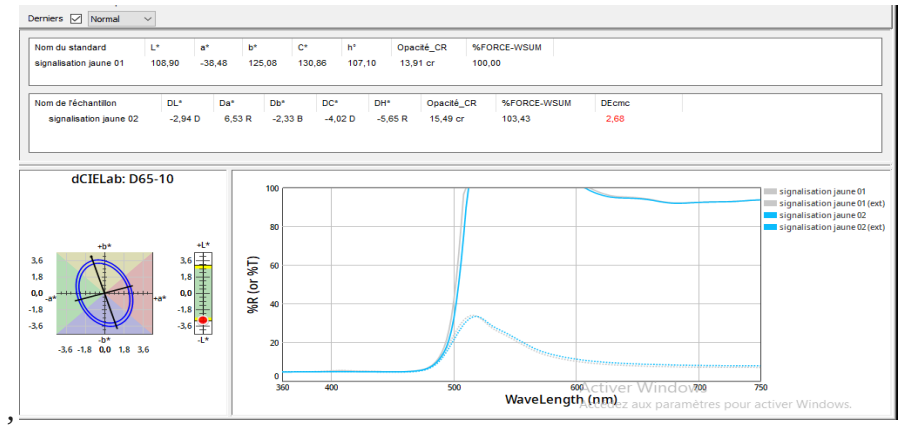


Figure 11 : Yellow pigment-based signaling

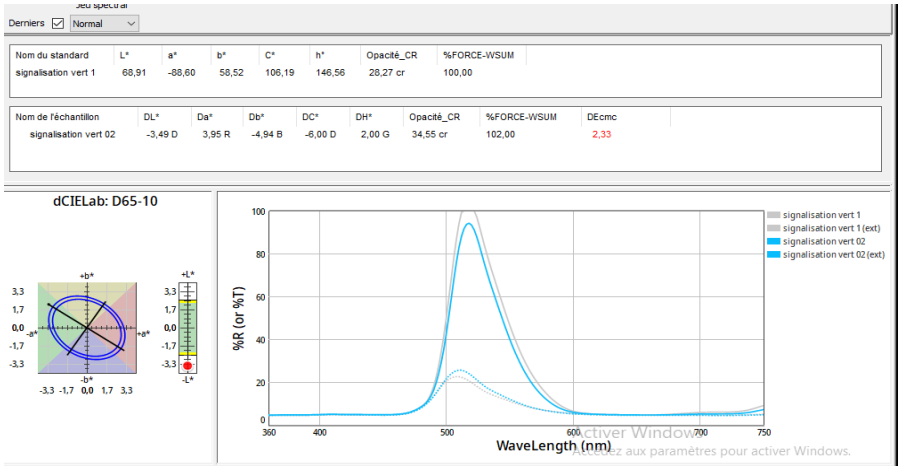


Figure 12 : Green pigment-based signaling

III.1.7. Influence on durability

The results show that the durability of fluorescent paint depends directly on its chemical composition and the balance between its components, particularly the resin (ligant), fluorescent pigment, and additives. The resin plays a crucial role in forming a continuous and cohesive layer that acts as a barrier, protecting the pigment from external factors such as water, UV radiation, and mechanical abrasion.

Scientifically, the paint's resistance to deterioration is related to the resin's ability to maintain its structure under harsh environmental conditions. The more homogeneous and cohesive the resin layer, the greater the paint's resistance to cracking or peeling when exposed to UV rays, humidity, or abrasion.

The fluorescent pigment also affects durability. An excessively high concentration can weaken the layer's cohesion due to a lack of binding material around the pigment molecules, creating internal weaknesses that facilitate deterioration over time. Conversely, good pigment dispersion within the resin medium helps improve stability and minimize these weaknesses. Additives such as anti-UV agents absorb or reduce the harmful effects of radiation, slowing the breakdown of polymer bonds within the resin and delaying the onset of color or mechanical degradation.

Therefore, the difference in durability between formulations can be explained by the complex interaction of the three components. Any imbalance among them leads to poor overall performance, while properly adjusting their composition significantly improves the coating's resistance to harsh environmental conditions.

III.1.8.Impact on mechanical properties

In this study, the mechanical properties of fluorescent coatings were evaluated through a series of tests, most notably adhesion and abrasion resistance. The results showed that the samples exhibited good adhesion to the substrate, with no noticeable peeling occurring during the strip test. This demonstrates the resin's effectiveness in achieving good bonding between the coating and the surface.

Regarding abrasion resistance, it was observed that after subjecting the samples to abrasion, some formulations, particularly thinner layers, experienced minor surface wear, while other samples remained more stable. This difference is attributed to variations in layer cohesion and pigment distribution within the resin.

Overall, these experiments demonstrated that the mechanical performance of the coating depends on the quality of the formulation and the balance of its components. Improved adhesion and dispersion result in a coating that is more resistant to mechanical stresses.

III.1.9.Comparison with a conventional paint

A comparison between fluorescent and conventional paint reveals fundamental differences in their optical, physical, and mechanical properties, primarily stemming from the nature of the pigment and the paint's composition.

Optically, conventional paint relies solely on light reflection thanks to pigments like titanium dioxide, while fluorescent paint absorbs and re-emits light instantly, resulting in higher luminosity and greater visibility, especially at night and under vehicle headlights. This explains the superior performance of fluorescent paint in traffic safety applications.

In terms of density, conventional paint has a higher density due to its heavy metallic pigments, whereas fluorescent paint contains lighter organic pigments, leading to a lower density. This difference impacts application; fluorescent paint is easier to spread and apply, but may suffer from poor coverage at lower thicknesses.

Regarding viscosity and dispersion, fluorescent paint is more sensitive, as any misalignment of the pigment can lead to particle clumping and a decrease in optical and mechanical performance. In contrast, conventional paint is more stable and less affected by these factors due to the nature of its pigments. Regarding mechanical properties and durability, conventional paint often exhibits higher resistance to corrosion and environmental factors, while the performance of fluorescent paint depends heavily on the quality of the resin and additives (such as UV inhibitors). Fluorescent pigments are more sensitive to ultraviolet radiation, which can lead to faster deterioration if the formulation is not optimized.

These differences can be explained by the fact that fluorescent paint primarily focuses on high optical performance (luminosity), while conventional paint offers greater mechanical and chemical stability. Therefore, the choice between them depends on the nature of the application, with fluorescent paint being a better option for traffic signals requiring high nighttime visibility, provided its formulation is optimized to ensure sufficient durability.

III.2.General Conclusion

The results obtained in this study highlight the significant impact of various formulation parameters on the overall performance of fluorescent paint for traffic signs. By preparing several formulations with different pigment percentages, it was demonstrated that the pigment content plays a crucial role in controlling the paint's optical behavior.

Increasing the fluorescent pigment content from 25% to 28% resulted in a significant improvement in luminescence intensity and CR (Chromatic Reflectance), confirming that a higher pigment content enhances optical performance. However, the change in the curve shape indicates that this effect is not entirely linear but is also influenced by the dispersion quality and the internal structure of the coating.

Physically, viscosity measurements using a viscometer (module 4, speed between 10 and 20 rpm) showed that the formulations exhibit stable rheological behavior, especially at solids contents exceeding 46%, ensuring easy application and the formation of a homogeneous coating. In terms of application, a thickness of approximately 120 micrometers was adopted, which, although relatively thin, allowed for a good evaluation of the optical properties while maintaining acceptable layer uniformity. Surface preparation also proved to play a significant role in improving adhesion and coating stability.

Regarding durability, the results showed good water resistance, with no observed changes after testing. UV resistance and accelerated aging tests also demonstrated acceptable coating stability, particularly due to the inclusion of UV-resistant additives, which contribute to preserving optical and mechanical properties over time.

Finally, the mechanical properties study showed that adhesion, cohesion, and abrasion resistance are highly dependent on the composition balance. Good pigment dispersion within the acrylic resin matrix contributes to improved resistance to mechanical stresses.

Overall, this study confirms that optimizing the coating composition, especially in terms of pigment ratio, dispersion quality, and the type of additives, is essential for achieving a high-performance fluorescent coating that combines good luminescence intensity with acceptable durability.

The experimental analysis of the different formulations shows that the overall performance of fluorescent coatings is directly related to the fluorescent pigment content within the resin matrix. It was observed that the formulation containing 28% fluorescent pigment achieves the best balance between optical, physical, and mechanical properties compared to the 25% formulation. From an optical point of view, increasing the pigment content leads to a clear improvement in luminous intensity and optical response for the yellow, green, and orange pigments, making them more visible under illumination and enhancing their effectiveness in traffic sign applications. The improvement in chromatic reflectance (CR) also indicates a higher efficiency in converting incident light into visible reflected light, which improves the overall optical performance without altering the color identity.

From a structural perspective, the increase in pigment concentration did not negatively affect coating homogeneity. The results show that pigment dispersion within the resin remained good, ensuring strong cohesion and stability of the coating layer. This indicates that the resin system and additives, particularly dispersing agents and stabilizers, were able to accommodate the higher pigment loading without agglomeration or internal structural weakness.

Regarding durability, water resistance, UV exposure, and accelerated aging tests demonstrated that the 28% formulation maintains good stability, with no significant degradation in color or surface properties. This confirms the effectiveness of UV stabilizers in protecting polymer bonds within the resin matrix and delaying photo-oxidative degradation.

From a mechanical standpoint, adhesion and abrasion resistance remained acceptable, indicating that the increase in pigment content did not weaken the coating structure. Instead, a proper balance between pigment and binder was maintained, ensuring mechanical integrity.

Therefore, the selection of the 28% fluorescent pigment formulation is considered optimal, as it provides a well-balanced combination of high optical performance (luminescence and reflectance), physical stability (dispersion and homogeneity), and durability under harsh environmental conditions, making it the most suitable option for fluorescent road marking applications.

In improving the performance of fluorescent paint for traffic signs, the integration of nanotechnology is a key modern approach to developing this type of material. This approach involves using extremely fine nanoparticles added to the formulation. These nano-particles are directly incorporated into the resin medium during the mixing stage, along with the fluorescent pigment and other additives, to enhance the paint's internal structure at the microscopic level.

These nano-particles promote more uniform pigment dispersion, reducing clumping and increasing light absorption and re-emission efficiency, thus improving luminosity. They also fill microscopic voids within the coating, resulting in a denser and more cohesive structure, which in turn enhances mechanical properties such as abrasion resistance and adhesion.

Furthermore, some advanced nanomaterials, such as nanometal oxides, can act as a protective shield against ultraviolet radiation. They shield the resin and pigment from photodegradation, extending the paint's lifespan and preserving its optical properties for a longer period. Therefore, incorporating nanotechnology into the fluorescent coating formulation not only improves a single property, but also contributes to raising the overall performance of the coating by improving dispersion, enhancing durability, and increasing stability under harsh environmental conditions, making this approach a step forward towards developing more efficient and intelligent traffic signal coatings.

References :

[1] : Company presentation PIGMA COLOR

[2]: Z,hangF et al(2024) . A luminate Long After glow Luminescent Materials in roed marking fieled , Research Progress and Devellopement . A review, Bulding , 14 (7),2152.

[3]: Khiter, K; Kabaci, I ; Medjdoub , W . Conception et évaluation des systèmes de peintures pour conteneurs au milieu marin. Mémoire Licence Université Akli Mohand Oulhadj de Bouira .(2024)

[4] : Frank N . Jones ; Mark E , Nichols . Socrates Peter Pappas . «Organic coating : Science and Technology .» 2017.

[5]: Elmejjatti , A. Optimisation de la Viscosité de peinture à l'eau par les plans d'expérience . Mémoire Master Université Sidi Mohammed Abdallah (morocco 2011)

[6] : Gacem, L . Rôle de l'agent mouillant de lq fabrication d'une peinture vinylique . Mémoire de licence Université Akli Mohand Oulhadj de Bouira. (2019)

[7] : Federal highway administration (Manual on uniform Traffic Control Device)

[8] : Jason,N ; Taylor , D . From streetlights to phosphore . A review on the visibility of roadway marking (Science Direct)

[9]:Nance, J., & Sparks, T. D. (2020). From streetlights to phosphors: A review on the visibility of roadway markings.

[10] : Technical Data sheet (ttc coating)

[11] : Andres .C , Luis . B , Jose A, and Selvador . I ; «In Situ Study of Road Marking Durability Using Glass Microbeads and Antiskid Aggrgates as Drop-on Materials » (MDPI)

[12] : What is fluorescence ? and how does it work ? (science lnsights)

[13] : M. Barletta a , G. Rubino b , V. Taglaferri a , S. Vesco a Show more ;«Design and manufacture of Photoluminescent coatings on stainless steel substrates » (Science direct).

[14] : Salvator, M ; Francesco, M ; Luca , R ; UV-Exated Fluorescence as a Basis for the In-situ identification of natural Binders in historical painting : A critical study on model samples (MDPI)

[15] : facteur (Study on Preparation of Long-Afterglow luminescent Road-Marking coatings and simulation of Road layout)

[16] : Luminescent properties of fluorescent color water-based ink films (Science direct)

[17] : Daylight fluorescent pigments in work of Art properties history , and fasting .

[20] : Weather and UV- resistance . Exploring the resilience of paints and coatings (Special chem) 2025

[21] : Wang, N., Li, Q., Zhang, L., Wang, J., 2025 .Anti-aging and durability performance of pavement markings under multifactor coupling effects (science direct)

[22] : Nguyen, P.T., Martin, J., Byrd, E., Embree, N., 2002. Relating Laboratory and outdoor exposure of coating . Effect of relative humidity on moisture enhanced photolysis of acrylic-melamine coatings (science direct)