

An Investigation into the Impact of Powder Types on Latex Dispersibility Index and Pigment Binding Capacity in Acrylic-Styrene Latexes

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ABSTRACT

The present study aims to explore the impact of different types of powder on the latex dispersibility index and pigment binding capacity in Acrylic-Styrene latexes. The methodology employed in this study involves investigating the latex dispersibility index by monitoring the Brookfield viscosity of pre-wetted powder when added to latex. Furthermore, the pigment binding capacity of the powders was evaluated through the wet scrub resistance of the latex paint. The findings from this study emphasize the importance of the size, shape, hydrophobicity, and hydrophilicity of powders in influencing the dispersibility of latex. Additionally, the physical and chemical properties of the powder also influence the binding strength between the powder and latex in the dried film. The implications of this study are discussed in terms of the ability to predict the powder-latex dispersion behavior using the viscosity-latex content curve for each type of powder. The results revealed that the maximum viscosity for the latex mixtures containing talc powder and calcium carbonate occurs at the amount of latex lower than 5 g. In contrast, the mixtures with titanium dioxide powder reach their maximum viscosity in the presence of higher than 10 g latex. Overall, this paper provides valuable insights into the characteristics of powders and their impact on the latex dispersibility index and pigment binding capacity in Acrylic-Styrene-based latexes. Prog. Color Colorants Coat. 17 (2024), 381-391 © Institute for Color Science and Technology.

1. Introduction

Coatings play a critical role in protecting and enhancing the appearance of various surfaces, including walls, vehicles, and appliances. Water-based coatings have become increasingly popular in recent years due to their environmental and health benefits. Unlike solvent-based coatings, water-based coatings do not release large amounts of volatile organic compounds (VOCs) into the atmosphere, which can contribute to air pollution and have negative health effects. The development of new technologies and formulations has further expanded the

capabilities and performance of water-based coatings, making them an important and versatile option for coating applications [1-4].

The performance of a water-based coating depends on many factors, including the type and quality of the latex, the choice of pigments, and the dispersion of the pigments evenly throughout the latex. Pigment binding capacity (PBC) and latex dispersibility index (LDI) are two important parameters for latex paint producers looking to optimize their coating formulations. There is a correlation between PBC and LDI in water-based

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coating formulations. Pigment binding capacity refers to the ability of a pigment to bind with the latex in the coating. In contrast, latex dispersibility index measures the ability of a latex to disperse pigments uniformly throughout a coating [5-7]. A higher LDI indicates that the pigment is more easily dispersed in the latex, which can lead to better pigment wetting and a more uniform coating film. A higher PBC indicates that the pigment is more efficiently bound to the latex, which can lead to better color and opacity with less pigment loading. Therefore, a formulation with a high LDI and high PBC is generally desirable for optimal water-based coating performance. By understanding the parameters affecting on LDI and PBC, water-based coating producers can develop coating formulations that deliver the desired performance characteristics while minimizing cost and reducing environmental impact. Moreover, viscosity is a crucial parameter in the formulation and application of latex paint.

The parameters affecting the viscosity of latex-powder mixtures would cover various aspects. The pigment volume concentration (PVC) in coatings and paints is known to affect viscosity. Higher PVC results in increased viscosity due to the greater amount of solid particles dispersed in the latex binder [8]. Studies have shown that the particle size distribution of powder pigments significantly impacts the viscosity of latex-pigment mixtures. A narrower particle size distribution leads to lower viscosity due to improved particle packing within the latex matrix [9]. Surface treatment of powder pigments plays a crucial role in influencing the rheological properties of latex coatings. Treatments such as silane modification help reduce particle agglomeration and enhance dispersion, leading to lower viscosity [10]. The shear rate applied during mixing and application processes affects the viscosity of latex-powder suspensions. Studies have demonstrated that viscosity decreases with increasing shear rate, indicating shear-thinning behavior essential for optimal flow properties [11]. Temperature variations can also influence the viscosity of latex-powder mixtures. Higher temperatures lead to reduced particle interactions, resulting in decreased viscosity of the formulation [12].

The interplay of interactions among the various materials and phases within mixtures influences their behavior [13-18]. The rheological properties of latex paints rely on the degree of dispersion of powders, which, among various other factors, is influenced by the

strength of interactions between the polymer matrix and powders. Latex-powder interactions encompass a myriad of mechanisms, including electrostatic forces, van der Waals forces, hydrogen bonding, and steric hindrance. Such interactions foster the formation of intricate particle networks or clusters within the mixture, fundamentally shaping its rheological properties. Moreover, the size and shape of both latex and powder particles emerge as pivotal factors influencing viscosity. Larger particles impede flow by creating greater obstruction, whereas smaller particles fill interstitial spaces, thereby contributing to viscosity. In the other words, the size of powder particles affects their surface area-to-volume ratio, which can influence their interaction with latex particles. Smaller particles typically have a higher surface area, allowing for better dispersion within the latex matrix. Furthermore, the shape of particles determines how they pack together, which in turn affects the formation of networks and ultimately influences viscosity. Surface chemistry further complicates the interplay between particles. Functional groups on particle surfaces can either promote or inhibit aggregation, profoundly affecting mixture viscosity. For instance, particles bearing polar functional groups may exhibit stronger interactions with latex particles, leading to increased viscosity. Additionally, the volume fraction and concentration of particles in the mixture play a key role in determining its viscosity. Higher particle concentrations typically result in elevated viscosity due to intensified particle-particle interactions and the formation of denser networks. At the critical dispersion concentration, viscosity is at a minimum, corresponding approximately to the point at which the zeta potential of the particles becomes constant [19].

Cheaburub et al. emphasized the significance of achieving a balance in coating applications between the powder type's compatibility (hydrophobicity/hydrophilicity) with the latex and the required emulsifier amount for emulsion stability, both of which impact the rheology and ultimate performance of the latex paint [20]. They discussed the rheological behavior of nanocomposite latexes made from butylacrylate-co-methylmethacrylate-co-acrylamide terpolymers with various commercial nanoclays. Tests were conducted to assess the impact of clay incorporation, type of clay, and emulsifier content on the properties of these materials. Results showed increased viscosity with clay addition, shear thinning at higher rates, and improved stability and

performance in leather finishing applications. The viscosity and dynamic modulus of the latex were also affected by the hydrophobic nature of the clay and the amount of emulsifier present.

Fournier et al. [21] researched the impact of dispersed phase viscosity on solid-stabilized emulsions. They established a relationship between emulsified oil volume, o/w viscosity ratio, power density (or Reynolds number), and agitation time. Additionally, they proposed the existence of capillary action between the dispersed phase (oil) and the particle at the interface. Lay et al. [22] aim to ascertain the approach for modifying the CaCO₃ particle size to enhance the dispersion of the filler in NRL films. Their findings reveal that an increase in viscosity occurs with a higher filler loading, primarily due to the hydrodynamic effect. This is because the introduction of unstrained particles into the polymer matrix leads to a higher viscosity of the rubber compound. Additionally, when the filler network reaches a certain level and secondary filler agglomeration occurs, it results in the formation of a weak filler network held together by Van der Waals forces. Furthermore, Karakas et al. [23] identified that the interaction between particles, guided by electrostatic attraction, is a key factor in determining paint quality. This electrostatic attraction is influenced by the surface charge of the particles within the pH range of the paint medium.

Several different methods have been proposed for measuring LDI. A new method was presented for determination of the latex dispersibility of pigments, called the "centrifugal sedimentation method". The method uses a centrifuge to separate the pigment particles from the latex binder, and the LDI is calculated as the ratio of the pigment mass in the centrifuge sediment to the total pigment mass. Khorasani et al. have proposed a new method for calculating LDI based on

minimum viscosity. They found that the composition of the monomers and emulsifiers had a significant impact on LDI [24]. However, the impact of mineral powders was the primary factor in determining the trend of viscosity vs. mass of the latex curves, with negligible variation based on the type of latex used.

In this paper, we investigate the pigment binding capacity and latex dispersibility index of four acrylic-styrene latex coatings with three different pigments: titanium dioxide, calcium carbonate, and talc. By studying these parameters, we aim to gain a better understanding of how the choice of pigment and latex composition affects the performance of coatings. One novel aspect of the work is the integrated approach, in which the study specifically employs a systematic method by combining measurements of latex dispersibility index and pigment binding capacity. By assessing both parameters, the research provides a holistic understanding of how different powders affect key properties of water-based coatings. In addition, the study systematically investigates the influence of powder characteristics such as size, shape, hydrophobicity, and hydrophilicity on latex dispersibility and pigment binding. By examining powders with diverse properties (titanium dioxide, calcium carbonate, talc), the research offers valuable insights into the role of powder characteristics in coating performance.

2. Experimental

The specifications of four commonly used commercial acrylic-styrene latexes in the water-based coating industry are presented in Table 1.

For this research, three different mineral powders, namely titanium dioxide (TiO₂), calcium carbonate (CaCO₃), and talc were selected. A summary of the specifications for these powders, as listed in their respective supplier data sheets, is presented in Table 2.

Table 1: Specification of commercial acrylic-styrene latexes.

Latex	Solid Content (%)	pH	Viscosity (cP)	MFFT* (°C)
<i>Acronal T 290 D</i>	50±1	7.5-9	700-1500	20
<i>Polyfam 707</i>	50±1	8-9	3500	16
<i>Polyco RSS-630</i>	50±1	7-9	8000-12000	<0
<i>Simacryl R-4410</i>	50±1	8-9	1000-2000	22

*MFFT: Minimum Film Forming Temperature

Table 2: Specification of the mineral powders.

Material	Particle size (μ)	Supplier	Country
TiO ₂	0.25-0.4	Crystal	Saudi Arabia Kingdom
CaCO ₃	10-12	Poudrsazan	Iran
Talc	18-20	Poudrsazan	Iran

The LDI of latexes was investigated using the method proposed by Khorasani et al. [24]. As a starting point, the powders were wetted using a predetermined amount of water. Subsequently, the dispersibility of the latex samples was assessed by gradually adding each latex as a dispersant to the 200 g of pre-wetted powder. After each incremental addition, the mixture was gently homogenized through mixing, and the Brookfield viscosity was subsequently measured (Figure 1 a). The addition of resin is continued until the viscosity of the mixture reaches a level of less than 20 cp. Applying this approach, a viscosity profile is constructed by correlating the quantity of latex used.

This profile serves as an analytical tool for evaluating the behavior and characteristics of both the latex and powder constituents.

Formulating the latex paints involves a careful balance of these considerations to develop paints that meet performance requirements, regulatory standards, cost constraints, and application needs. The formulation used in this work was an economical, well-known industrial formulation with a minimal amount of latex to observe the effect of powder type on LDI. By using a lower amount of latex, one could better distinguish the influence of powder type on the washability results, which arise from binder-powder interactions.

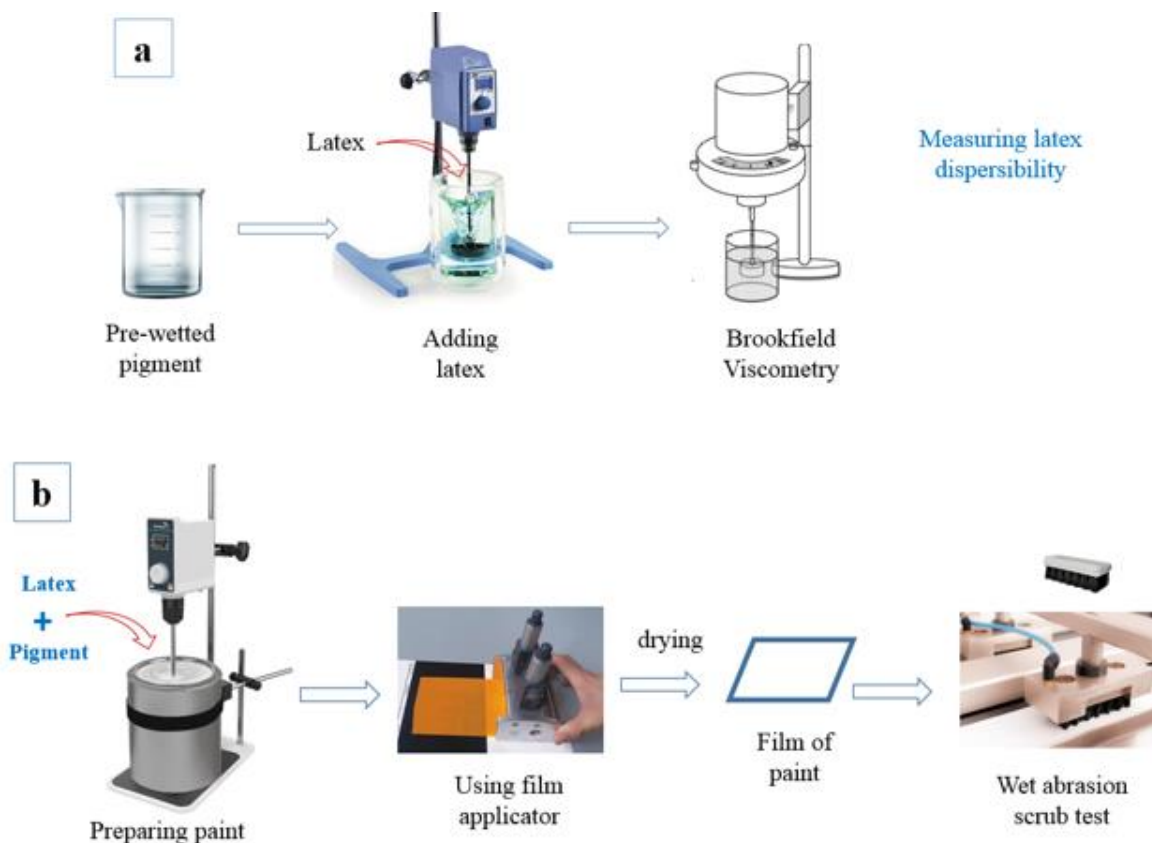


Figure 1: a) Procedure for measuring latex dispersibility index and b) operation for preparing films of paints and then measuring pigment binding capacity.

To study pigment binding capacity, twelve paint samples were made with three kinds of pigments and four different latex resins. The paints were placed in containers with closed lids. Then, a paint applicator was used to cover a 120 μm thickness of the paint films on a surface. The relative humidity of the laboratory was about 20-25 %. The prepared paints samples were kept for a week in the laboratory environment until they were completely dry. The pigment binding capacity was determined by subjecting the latex paints containing pigments to a wet scrub resistance test (Figure 1b). The wet scrub resistance test was performed in accordance with the ASTM D 2486 standard test method for latex paints [25]. Accompanied by a description of their respective functions, a list of the additional materials utilized in the preparation of the latex paint is presented in Table 3.

The loss weight of the samples is calculated by equation 1 according to ASTM D2486.

$$Loss\ weight = \frac{W_0 - W_f}{W_0} \times 100 \quad (1)$$

Herein, W_0 and W_f correspond to the weight of the coated panel before testing and after testing, respectively. The amount of material lost from the latex paint due to abrasion during the test is taken as a measure of the coating's resistance to abrasion and its ability to bind pigment. The correlation between wet scrub resistance and PBC is based on the fact that coatings with a higher PBC typically exhibit better adhesion between the pigment particles and the binder, resulting in improved resistance to abrasion and scrubbing. As a result, a coating with a high wet scrub resistance value (low loss weight) is generally considered indicative of a good pigment binding capacity.

3. Results and Discussion

The changes in viscosity resulting from the addition of latex for four types of latex and three powders, including talc, calcium carbonate, and titanium dioxide, are presented in Figure 2. It depicted a consistent viscosity trend directly influenced by the characteristics of the powders.

The introduction of latex as a dispersant to the pre-wetted pigment causes an alteration in the volume of the

dispersed phase, primarily attributed to the presence of polymer particles. Unlike mineral particles, latex particles possess a lower level of rigidity and exhibit an affinity for adhering to the mineral particles. As a result, the latex particles adsorb onto the surfaces of the pigment particles, leading to the formation of aggregates characterized by the amalgamation of sticky pigment particles and latex, which is known as latex-pigment aggregation. This phenomenon initially increases viscosity due to the adsorption of dispersant molecules onto the pigment particles. The adsorbed molecules form a protective layer around the pigment particles, promoting increased inter-particle interactions and overall viscosity uprise. However, there exists an optimal amount of dispersant that should be added. Beyond this point, the additional latex dispersant can decrease paint viscosity, as the excessive dispersant disrupts the structure formed by the pigment particles and dispersant molecules, thereby reducing inter-particle interactions [26, 27].

Regarding talc, the viscosity initially demonstrates a low level and exhibits a gradual increase as the amount of latex is increased, albeit to a slight degree. However, upon further substantial additions, the viscosity begins to decrease. It is noteworthy that talc displays minimal changes in viscosity throughout this process.

Table 3: Latex paint compositions.

No.	Material	TiO ₂	CaCO ₃ /Talc
1	latex	43.56	44
2	Anti-foam	0.4	0.2
3	Anti-fungal	0.06	0.06
4	Film former	1.39	1.4
5	Dispersing agent	0.79	0.8
6	Pigment	32.67	21.6
7	Wetting agent	0.4	0.4
8	Diluent	20.13	30.54
9	Thickener	0.6	1

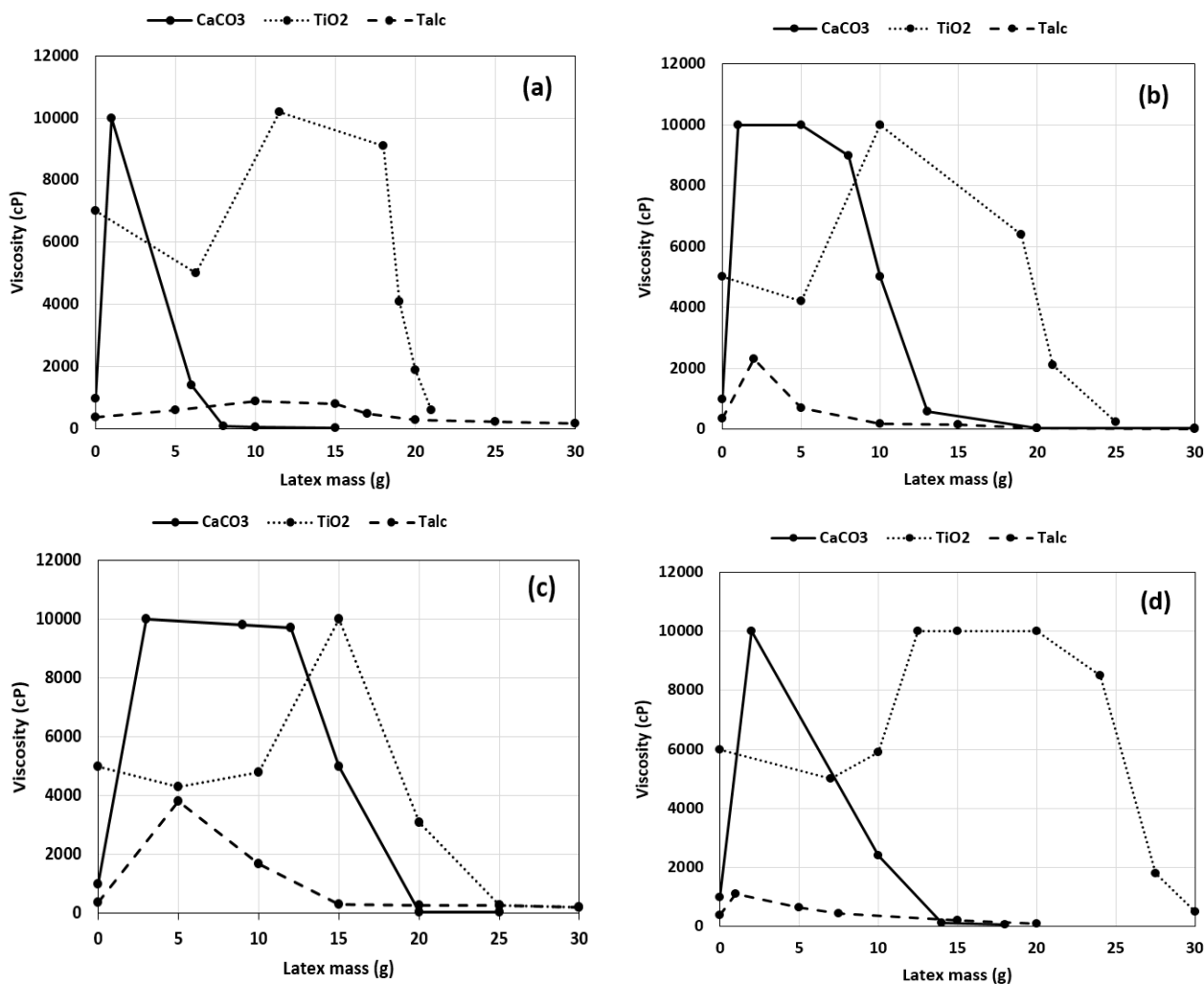


Figure 2: Effect of latex content on the viscosity of pre-wetted powders: a) Simacryl R-4410, b) Polyfam 707, c) Polycy RSS-631 and d) Acronal T 290 D.

Talc's molecular structure consists of sheets of magnesium hydroxide bonded to silica, resulting in its hydrophobic nature primarily attributed to the siloxane (Si-O-Si) surfaces that repel water. This hydrophobicity causes talc particles to aggregate in aqueous environments, and to minimize their contact with water, affecting their dispersibility. The hydrophobic characteristics of talc limit the formation of strong interactions between dispersed (powder) and dispersing (latex) phases. Consequently, at low latex concentrations, the viscosity does not significantly increase. However, as the latex concentration, acting as a dispersant, increases, the limited interactions initially formed are further diminished, leading to a decrease in

viscosity [28, 29]. This phenomenon is observed due to minimal water uptake occurring through talc plate-like shape particle. As a result, the presence of hydrophobic talc particles with large size does not significantly alter the system's viscosity.

TiO₂ demonstrates a semi-sinusoidal behavior whereby the addition of latex initially leads to a reduction in viscosity [30]. Nevertheless, upon the incorporation of a larger quantity of latex, the viscosity subsequently increases. In the end, when a significant amount of latex is added, there is a subsequent decrease in the viscosity of the TiO₂ system. The underlying mechanisms responsible for these viscosity changes are likely governed by factors such as particle-

particle interactions, latex conformation, and the formation of aggregated structures within the composite system. The titanium dioxide particles exhibit a small and spherical morphology, resulting in a significantly high specific surface area [31]. Additionally, their hydrophilic nature makes them prone to agglomeration. When latex is added as a dispersant to the pre-wetted titanium dioxide, it effectively reduces viscosity by disrupting the inter-particle bonds formed among the pigment particles. Moreover, by increasing the concentration of latex and enhancing its absorption onto the surfaces of pigment particles, the viscosity increases accordingly. However, similar to the behavior observed with talc, a higher concentration of latex can excessively disrupt the structure formed by the pigment particles and dispersant molecules, leading to a decline in inter-particle interactions and thus decreasing the viscosity [32].

In the case of CaCO_3 , the viscosity initially increases upon the addition of latex and then reaches a relatively constant level, forming a plateau. Subsequently, the viscosity decreases. This initial plateau suggests the presence of a stable dispersion or the formation of a temporary network structure, which contributes to the observed viscosity stability [22]. However, as the system becomes less concentrated through dilution, the structure gradually breaks down or rearranges, resulting in a subsequent decrease in viscosity. The high specific surface area of spherical calcium carbonate particles and their hydrophilic nature facilitate enhanced adsorption of latex particles onto their surfaces. With an increasing concentration of latex, there is no formation of novel structures that contribute to viscosity enhancement. However, the existing structures formed by the interaction between pigment and polymer particles exhibit stability. This phenomenon is also observed, albeit to a lesser degree, with spherical and hydrophilic titanium dioxide particles. This decline which also was observed for TiO_2 and Talc system can be attributed to the disruption of the microstructure and rheological properties caused by the excessive presence of latex. The higher concentration of latex destabilizes the dispersion or network structure formed by mineral powders, causing it to break down or undergo rearrangement. Consequently, the viscosity of the system decreases [33].

A closer examination of Figure 2 reveals interesting observations regarding the impact of powder types on the viscosity of the latex mixtures. Specifically, it is

evident that the maximum viscosity for the mixtures containing talc powder and calcium carbonate occurs at lower amount of latex as a dispersant (that is lower than 5 g latex). In contrast, the mixtures with titanium dioxide powder reach their maximum viscosity in the presence of more latex (that is higher than 10 g latex). The higher concentration of latex required to reach the maximum viscosity with titanium dioxide implies a better dispersibility and interaction between the latex binder and the titanium dioxide particles. These findings suggest that the dispersion behavior of the same latexes is enhanced in the presence of titanium dioxide powder compared to talc powder and calcium carbonate. The higher concentration of latex needed for maximum viscosity in titanium dioxide mixtures holds significant implications for coating formulation and performance. This phenomenon suggests that titanium dioxide particles exhibit a greater propensity to disperse within the latex matrix and interact with the latex particles than other powders, such as calcium carbonate or talc. The need for a higher latex concentration to achieve maximum viscosity indicates that titanium dioxide particles require more extensive coverage and interaction with the latex matrix to form stable networks and increase viscosity effectively. This suggests that titanium dioxide particles have a higher dispersibility within the latex matrix, allowing them to be more uniformly distributed and effectively integrated into the coating formulation. Furthermore, the increased latex concentration required for maximum viscosity implies stronger interactions between the latex and titanium dioxide particles. These interactions likely involve adhesion, aggregation, and bonding between the latex binder and the titanium dioxide particles, facilitating the formation of dense networks and enhancing viscosity. This relationship is crucial for achieving optimal coating performance, including improved pigment dispersion, film formation, and coating properties as washability which will be investigated in the following section.

A series of 12 latex paints were formulated following the compositions outlined in Table 3, aiming for a target Pigment Volume Concentration (PVC) of 25 %. With this amount of PVC, the proper ratio of pigment to binder was ensured for all three types of powder, and it was a desirable minimum amount. Moreover, our desired concentration was for an acrylic glossy paint, considering the variety in the selected powders, taking into account the polymer absorption of

all three powders and aiming to investigate the effect of powder type on LDI and PBC, in this work the PVC amount was set to 25 % for all the samples. The washability or wet scrub resistance refers to the paint film's ability to withstand scrubbing or wet abrasives without losing significant paint components from the surface of the underlying material. The performance of latex, pigments, and additives as a protective layer significantly influences the paint film's ability to shield the substrate from scrubbing or wet abrasives [34]. This study aimed to examine the influence of powder type on wet scrub resistance and pigment binding capacity. To isolate the specific effect of powder type, the binder and paint formulation were kept constant throughout the experiment [35].

The results obtained from the pigment binding capacity tests are presented in Figure 3. These tests were conducted to evaluate the ability of the pigments to bind within the latex paint formulations. The binding capacity of a pigment depends on various factors, including its physical and chemical properties such as particle size, shape, surface area, and surface chemistry. Additionally, interactions between the pigment and the latex binder present in the paint formulation play a crucial role [36, 37].

As depicted in Figure 3, titanium dioxide (TiO_2) exhibited the highest wet scrub resistance among the

tested pigments. This can be attributed to TiO_2 particles having a greater surface area and stronger binding ability with the latex binder than calcium carbonate (CaCO_3) particles. Consequently, TiO_2 forms a stronger and more cohesive film, which resists wear and tear during the wet scrub test. Furthermore, TiO_2 particles demonstrate higher resistance to moisture and alkalinity than CaCO_3 particles, mitigating degradation and weakening of the paint film over time [38]. The stronger binding ability of titanium dioxide (TiO_2) particles with the latex binder compared to calcium carbonate (CaCO_3) particles can be attributed to several specific mechanisms and interactions. TiO_2 particles typically have a higher surface area per unit volume than CaCO_3 and talc particles due to their smaller particle size and irregular shape. This increased surface area provides more sites for interaction with the latex binder, leading to stronger binding between TiO_2 particles and the binder molecules. Furthermore, TiO_2 particles typically have a more chemically active surface compared to CaCO_3 particles. TiO_2 surfaces may contain hydroxyl groups (-OH) or other functional groups that can form strong hydrogen bonds with functional groups present in the latex binder. These hydrogen bonds enhance the adhesion between TiO_2 particles and the latex binder, leading to stronger binding.

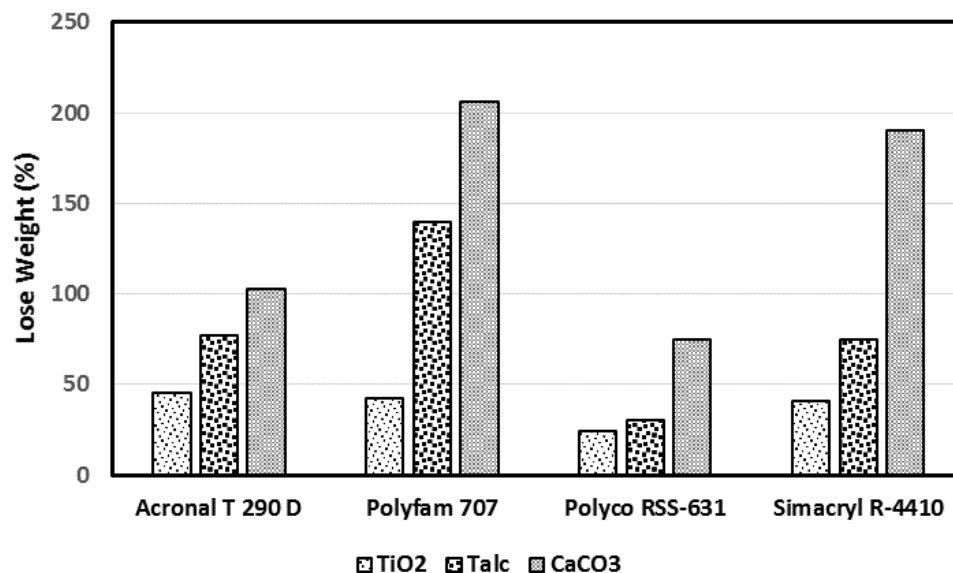


Figure 3: Effect of powder type on wet abrasion scrub resistance of coatings.

Talc, due to its excellent lamellar structure and platelet morphology, imparts enhanced durability and resistance against mechanical stress during scrubbing. The plate-like particles of talc interlock, leading to the formation of a more robust paint film and, consequently, improved wet scrub resistance. Conversely, the irregular particle shape of calcium carbonate, lacking the platelet structure found in talc, contributes to its relatively lower wet scrub resistance. Moreover, calcium carbonate has a solubility of approximately 0.013 g/L in water at room temperature. Consequently, a small amount of calcium carbonate dissolves in pure water at this temperature, further hindering its binding capacity in the paint formulation. The solubility of calcium carbonate in water can weaken the paint film by reducing the adhesion between the pigment particles and the binder matrix. This may lead to issues such as cracking, peeling, or flaking of the paint film over time, and as shown in this paper, reduces washability.

Interactions between the pigment and the latex binder have a significant influence on the pigment binding capacity within the paint formulation. The pigment binding capacity refers to the ability of pigment particles to bind with the latex binder and become incorporated into the paint film. These interactions play a crucial role in determining the overall performance of the paint formulation. Strong interactions between the pigment particles and the latex binder are essential for ensuring that the pigment becomes effectively bound within the paint film. Adhesion refers to the attraction between the pigment surface and the binder molecules, while binding involves the formation of chemical or physical bonds that secure the pigment in place. Enhanced adhesion and binding promote better pigment

dispersion and prevent pigment settling or migration within the paint film.

Effective interactions between the pigment and the latex binder contribute to the dispersion stability of the paint formulation. Proper dispersion ensures uniform distribution of pigment particles throughout the paint matrix, resulting in consistent color, opacity, and coverage. Without adequate interactions between the pigment and binder, pigment agglomeration or flocculation may occur, leading to uneven color distribution and compromised performance. Well-bound pigment particles contribute to forming a cohesive and continuous paint film with good adhesion to the substrate. This ensures long-term durability, resistance to cracking, peeling, and weathering, and overall protection of the substrate.

4. Conclusion

The addition of different powders, including talc, calcium carbonate, and titanium dioxide, influences the viscosity of the latex when used as a dispersant. Talc exhibits minimal viscosity changes, while TiO₂ shows a semi-sinusoidal behavior, and CaCO₃ demonstrates a plateau followed by a decrease in viscosity at higher latex concentrations. Furthermore, the pigment binding capacity tests reveal that TiO₂ exhibits the highest wet scrub resistance among the tested pigments due to its greater surface area and stronger binding ability with the latex binder. Talc, with its lamellar structure and platelet morphology, enhances durability and resistance against mechanical stress during scrubbing. On the other hand, calcium carbonate, with its irregular particle shape and water solubility, exhibits relatively lower wet scrub resistance.

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