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PROTOTYPING A COATING BASED ON ANCIENT TECHNOLOGY: A CASE STUDY IN SIGIRIYA, SRI LANKA

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ABSTRACT

This paper presents a study on prototyping a coating based on ancient technology, specifically focusing on the techniques used in Sigiriya, an ancient rock fortress located in Sri Lanka. Sigiriya stands out for its remarkable paintings and innovative hydraulic systems, emblematic of an advanced ancient civilisation. Through an interdisciplinary approach merging archaeology, materials science, and chemistry, this research seeks to understand and replicate the coatings found on the Sigiriya paintings. By analysing the composition and properties of these coatings, a modern prototype was developed that mirrors the characteristics of the ancient coatings, offering insights into their longevity and preservation methods. The experimental emphasis of the research is on the production of a natural surface coating utilising wood apple gum and other natural extracts. The methods included coating formulation, application, and testing. There were five treatments in the study, each with different ratios (20%,40%,50%,60%, and 80%) of wood apple (Limonia acidissima) gum, Dorana (Dipterocarpus glandulosus) oil, sesame (Sesamum indicum)oil and Haldummala (Trachylobium verrucosum) mixes. This investigation explored the basic performance properties of coatings, looking closely at water resistance, viscosity, adhesion, pH levels, and aesthetic appeal. However, in treatment T1, the ratio of 20:80 of water: Dorana oil exhibited exceptional adhesion properties and displayed the maximum hardness level (8H). Some treatments also showcased promising indications of water resistance. The findings of this study hold the potential to significantly impact various sectors by providing eco-friendly alternatives, fostering innovation, creating cultural business prospects, and upholding traditional values.

Keywords: *Ancient Coatings; Paintings; Sigiriya; Wood Apple Gum.*

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1. INTRODUCTION

The ancient city of Sigiriya, located amidst the lush forests of Sri Lanka, stands as a testament to its creators' ingenuity and artistic prowess (Ranasinghe, 2023). Among its many wonders are the vibrant paintings adorning the rock face, showcasing the artistry of an ancient civilisation (Dissanayaka & Arachchi, 2018). These paintings, along with the complex hydraulic systems and architectural marvels, continue to intrigue researchers and historians alike (Davids,1875; Silva, 2002; Subasinghe & Karunaratne,2022).

The Sigiriya paintings exhibit similarities to the Gupta style of painting seen in the Ajanta Caves of India. This similarity is not surprising, considering the geographical proximity of the two regions and the shared Buddhist faith during the 5th century. Scholars have referenced works by Silvat (1975), Somathilake (2002), and Nishanthi (2021) in support of this observation. However, despite this influence, the Sigiriya paintings are distinguished by their pronounced vibrancy, fluidity, and lifelike qualities compared to the paintings found in the Ajanta Caves. These Sigiriya artworks provide a rare glimpse into the pinnacle of ancient Sinhala artistry, as noted by Somathilake (2007). Particularly striking is the bold portrayal of well-defined bodies, ample bosoms, and full lips, which carries an unusually provocative tone (Subasinghe & Karunarathna,2022). Notably, these paintings constitute the sole instance of non-hidden female sensuality depicted in Sri Lankan art, as opposed to the strictly stylised representations of female figures with religious themes that predominate. Therefore, the Sigiriya paintings possess a distinctly Sri Lankan character. Furthermore, Subasinghe and Karunarathna (2022) emphasise that these paintings are the only surviving examples of secular, non-religious art from antiquity found in Sri Lanka today.

The paintings of Sri Lanka are predominantly recognised as religious art; however, the Sigiriya paintings stand out as temporal, as noted by Coomaraswamy (1907). Although historical records mention 25 paintings, few remain in the primary painting area today. These paintings predominantly feature female figures depicted with fair (yellow, golden yellow) or dark (ruddy, greenish) complexions. The main cluster of frescoes appears on the western face of the Sigiriya rock, specifically in the two rock chambers known as A and B, located approximately fifteen yards above the gallery floor near the rock's southern end (Subasinghe & Karunarathna, 2022). Cave 67.6 feet long is divided into two sections, A (26 feet 3 inches) and B (41 feet 3 inches), by a narrow ledge. Cave A is relatively spacious, while Cave B is taller and offers enough room to stand upright, except towards the end. The techniques employed in the Sigiriya paintings have sparked conjecture and controversy. Mr. Dhanapala proposed that the paintings were executed using the Fresco Bueno technique, whereas Dr. O.P. Agrawal and Dr. Nanda Wickramasinghe suggest they represent the Fresco Lustro technique (Agrawal, 2002:122). Additionally, some scholars believe they were created using the tempera technique. R.H. De Silva introduced a different perspective, suggesting the Sigiriya paintings were made using an "oil emulsion tempera with gum" technique (Seneviratne, 2018).

Utilising contemporary scientific methodologies, precise data was obtained regarding the mixtures, pigment bindings, and the presence of organic and inorganic chemicals used in Sigiriya paintings (Seneviratne, 2018; Seneviratne, 2020). This data was further scrutinised in the study conducted by Rathnayake et al. (2024). Consequently, a comprehensive understanding of the knowledge disseminated by scholars, both documented and undocumented, from various painting generations was achieved.

Numerous local and international researchers have utilised these findings to discern the ancient techniques employed by past painters (Seneviratne, 2018; Seneviratne, 2020; Rathnayake et al., 2024). Above studies have led to a robust understanding of the knowledge and techniques from various generations of painters, both documented and undocumented.

Despite the detailed understanding of the composition and techniques of ancient Sigiriya paintings, there is a lack of practical application of this knowledge in creating modern prototypes that replicate these ancient coatings.

Specifically, there is a need to bridge the gap between historical knowledge and contemporary application by developing a modern prototype that not only replicates but also demonstrates the performance properties of the ancient coatings. This paper, therefore, explores the research and development undertaken to construct a modern prototype that replicates the attributes of ancient coatings. Additionally, it presents the performance properties of the developed prototype, which is the innovative product under discussion in this paper. The study goes beyond theoretical analysis by applying historical knowledge to develop a modern prototype of ancient Sigiriya coatings. This transition from understanding to application is novel as it demonstrates the practical feasibility and performance of ancient techniques in a contemporary setting.

2. LITERATURE REVIEW AND CONCEPT

The Sigiriya paintings depict celestial maidens in graceful poses, painted with a remarkable level of detail and vibrant colours. The durability of these paintings over centuries points to the advanced techniques employed by the ancient artisans. Central to their preservation is the protective coating applied over the paintings, shielding them from weathering, humidity, and other environmental factors (Subasinghe & Karunarathna, 2022).

As noted by Seneviratne (2018) and Seneviratne (2020), traditional artists in Sri Lanka historically utilised Wood apple gum (Feronia Elephantum) for safeguarding the Sigiriya paintings. The Wood apple tree, indigenous to the Indian subcontinent and Southeast Asia, produces a clear, bright, and brown-coloured gum as a byproduct of specific plant and tree metabolic processes (Hossain et al., 1994). Natural gums derived from plants are either soluble in water or absorb water to create a viscous solution (Rodrigues et al., 2018). Among the essential resins employed in Sri Lankan art, Wood apple resin holds significant importance. Feronia gum is regarded as equivalent to gum Arabic in the context of varnishes and paints (Hossain et al., 1994). It serves as a substitute or adulterant for gum Arabic and finds use in artistic endeavours (Rodrigues et al., 2018).

Moreover, the research findings indicate the presence of minute quantities of Wood apple gum, Sesame oil, and Dorana Oil in the Sigiriya painting samples (Seneviratne, 2020; Rathnayake et al., 2024). It is evident that the use of oil as a medium for outdoor work, as observed in the late medieval period paintings of Sri Lanka, was crucial for their preservation. Without it, their longevity would be difficult to comprehend. According to Rathnayake et al. (2024), the ancient Sigiriya painters employed a chemical crosslinking process. This process involved the use of Wood apple gum (a water-soluble resin) and Dorana oil (a vegetable oil), catalysed by heat, oxidizing agents, and/or driers. This specific technique endowed the coating with increased durability, making it resistant to water solubility post-application. Haldummala was used as a thickening agent.

3. METHODOLOGY

The methodology of this research adopts a two-step approach, encompassing prototype development based on existing literature and performance analysis. The process is primarily organised into the following steps:

1. Prototyping based on literature, and
2. Studying basic performance properties.

The formulation of coating compositions generally involves four essential components: binder, solvent, pigment, and additive (Streit-Berger & Goldschmidt, 2018). In the preliminary development phase, this study selected Haldummala, Dorana oil, Wood apple gum, and Sesame oil for the coating formulation. Previous studies by Rathnayake et al. (2024) and Seneviratne (2020) provided material clarification for coating purposes. In this study, the identification of materials was followed by their classification based on purpose. After that, performance criteria were experimentally analysed by varying two variables: the aqueous plant gum solution to oil ratio using the 2 oils, Dorana and Sesame.

3.1 DEVELOPMENT OF MODERN PROTOTYPE

Seneviratne (2018) identifies the coating layer of Sigiri paintings as containing a water-soluble compound that turns into a white, fluffy substance with excess ethanol, indicating the presence of vegetable gum. Additionally, the binding medium features a drying oil that is insoluble in water but dissolves in ethanol, carbon tetrachloride, and chloroform. Seneviratne (2018) also utilised Gas Chromatography-Mass Spectrometry (GCMS) to detect wood apple gum and Dorana oil in the protective layer, concluding that it mainly consists of Dorana oil. This finding suggests that the paint layer mixed with Dorana oil may have degraded over time.

Building upon the insights gained from the analysis of the ancient coatings, a modern prototype was developed in this study. This study selected the method adopted in the study of Rathnayake et al (2024). As per the above studies, Haldummala, Dorana oil, Sesame oil, and Wood apple gum is used for coating formulation. Further in this study, two oils; Dorana and Sesame were identified as the crosslinking binding additives. Meanwhile, water as the solvent, wood apple gum as the binder, and Haldummala as an additive.

The formulation of the modern prototype drew inspiration from the following key components identified in the ancient coating:

- **Natural Resins:** Extracts from Wood apple trees, known for their adhesive and protective properties.
- **Mineral additives:** Haldummala consists of minerals such as Silica and Magnesium Carbonate, providing thickening properties (Subasinghe et al,2019).
- **Organic crosslinking oils:** Sesame oil and Dorana oil, contributing to the cohesive structure of the coating.

In the experimental phase, a quantity of 20g of each type of plant gum was dissolved in 500 mL of water, following the methodology outlined by Rathnayake et al. (2024). The dispersion method was employed to dissolve an equivalent quantity of Dummala in

Dorana oil for comparative analysis, thereby maintaining uniform concentrations across both substances. Subsequently, the two prepared solutions were subjected to a temperature of 80°C to facilitate thorough mixing with the previously mentioned additives. This procedure was replicated for Sesame oil. The study incorporated nine treatments, each characterised by varying ratios (20%, 40%, 50%, 60%, and 80%) of Wood Apple Gum (WG), and Haldummala combined with Dorana oil and Sesame oil, respectively as shown in Tables 1 and 2.

Table 1: Solution ratios with Dorana oil

Treatment abbreviation	WG solution: Dorana oil (ml)
T1	40:160
T2	100:100
T3	120: 80
T4	160: 40

Table 2: Solution ratios with Sesame oil

Treatment abbreviation	WG solution: Sesame oil (ml)
T1	40:160
T2	80:120
T3	100:100
T4	120: 80
T5	160: 40

The objective was to create a coating that not only mimics the appearance of the original but also offers enhanced durability and protection for contemporary applications. In this study, planed specimens of Soil-based wall care putty developed from drinking water treatment plant waste alum (Patent no. 21020) were used to apply the developed coatings. This wall care putty is a novel sustainable material known mostly for its good workability, properties, and appearance similar to the Sigiriya mirror wall. A total of 9 samples were used for the experiment and they were grouped as presented in Tables 1 and 2. The prepared wall care putty samples were applied with 9 coating treatments as in Table 3. The specimens underwent a conditioning period of 7 days in an environment maintained at a temperature of 20 ± 2 ◦C and a relative humidity of 50% ± 5% before the execution of any tests.

Table 3: Experimental design of the prototype

	Experimental Design	
	Dorana oil as crosslinking additive	Seasme oil as crosslinking additive
No.of samples	4 samples	5 samples
Coating system	Brush application	Brush application
Coating formulae	10% binder with a 20% dilution with water during application	10% binder with a 20% dilution with water during application
Applied surface	Patent no. 21020 - soil-based wall care putty	Patent no. 21020, soil-based wall care putty

	Experimental Design	
	Dorana oil as crosslinking additive	**Seasme oil as crosslinking additive**
Coating application	2- coat application with a light 2000-grit sanding between	2- coat application with a light 2000-grit sanding between
Tested properties	1)Adhesion test 2)Water resistance test 3) Hardness test 4) Viscosity 5) pH value 6)Visual appearance	1)Adhesion test 2)Water resistance test 3) Hardness test 4) Viscosity 5) pH value 6)Visual appearance

3.2 TESTING OF PERFORMANCE PROPERTIES

The modern prototype underwent rigorous testing to assess its performance and characteristics:

- **Adhesion Tests:** ASTM D3359 represents the standard testing procedures for evaluating adhesion through a tape test. This examination measures the adherence of film coatings to metal substrates by applying and subsequently removing a pressure-sensitive tape over incisions made in the film. This testing methodology is commonly referred to as the Cross Hatch test.
- **Hardness Tests:** ASTM D3363 represents the standard procedure that involves assessing the surface aesthetics of a coating after trying to inflict a scratch on it using a pencil of a specific hardness, angled at 45 degrees, and applying a steady force.
- **Water resistance:** ASTM D870 testing procedure involves submerging coated samples in water within a container that resists corrosion. Observations are made and reported regarding any alterations in color, the formation of blisters, loss of adhesion, softening, or embrittlement.
- **Viscosity:** Krebs Stormer viscometer was used to measure the viscosity as described in ASTM D562.
- **pH Value:** pH value was measured using a laboratory pH meter.
- **Visual appearance:** The inspection area was set up with consistent lighting conditions, ideally utilising natural daylight. The inspection area was ensured to have a neutral background to eliminate potential visual distraction. Each coated sample was individually examined with care.

4. RESULTS

One way ANOVA was carried out to identify the significant difference between tested nine treatments considering their pH values, viscosity, adhesion properties, hardness and water resistance. Significance of difference was defined at $p\text{-value} < 0.05$. Minitab17 was used to perform the statistical analysis.

4.1 VARIATIONS ACCORDING TO THE ADHESION

The effectiveness of coatings adhering to surfaces is influenced by a multitude of factors. It includes the compatibility of the substrate, the preparation of the surface, the formulation of the coating, the methods of application, the conditions under which curing occurs, environmental factors, and the age of the coating (Chen et al., 2014). To ensure that coatings provide effective protection and maintain their aesthetic appeal over time, it is crucial to achieve consistent adhesion (Chen et al., 2014). The delivery of high-quality coatings that exhibit reliable and robust adhesion necessitates a comprehensive understanding of these variations and the implementation of appropriate testing, formulation, and application strategies. Zero to seven increase the adhesion ability. The highest adhesion level shows higher performance. Adhesion performance variations are shown in Figure 1. T1, T9, and T2 showed the best adhesion.

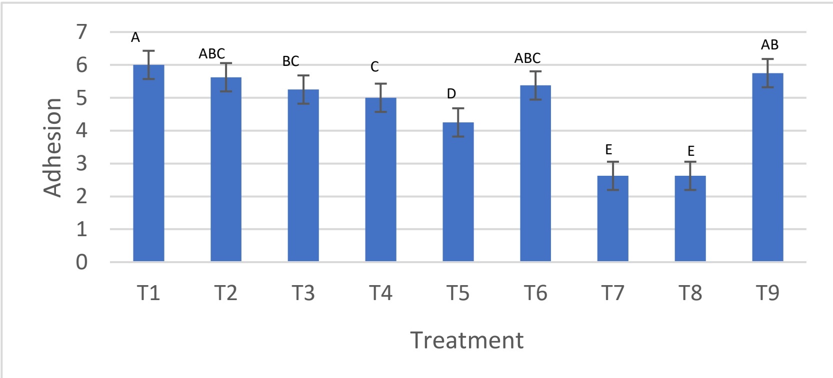

Figure 1: Adhesion vs Treatments

*(*Vertical bars indicate the standard errors of the mean adhesion (n = 3), Means that do not share a same letter are significantly different according to Ducan Multiple Range Test (DMRT))*

4.2 VARIATIONS ACCORDING TO THE HARDNESS

Several factors such as the composition of the coating, conditions under which curing is performed, thickness of application, adhesion, texture, dispersion of particles, flexibility, age, and the methodologies employed for testing, can potentially influence the outcomes of the pencil hardness test (Kim et al,2016). Gaining insights into these variations can aid in the development and optimisation of coatings for specific uses by shedding light on crucial aspects of the mechanical properties and longevity of the coatings. (Kim et al., 2016). Hardness performance variations are shown in Figure 2. T1, T3 and T2 shows the highest hardness value and there is a significant difference between other coatings.

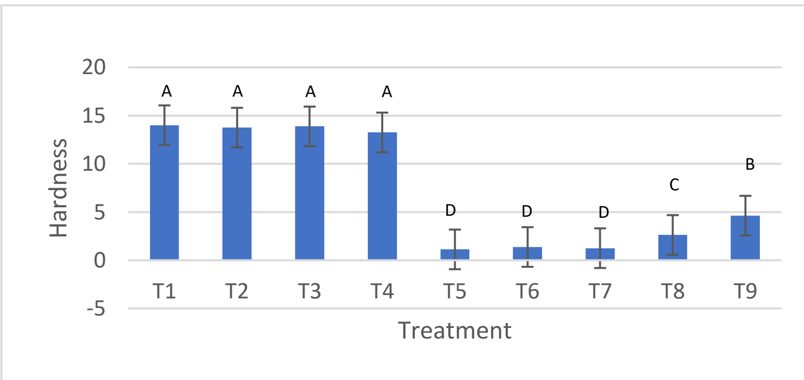

Figure 2: Hardness vs Treatments

*(*Vertical bars indicate the standard errors of the mean Hardness (n = 3), Means that do not share a same letter are significantly different according to Ducan Multiple Range Test (DMRT))*

4.3 VARIATIONS ACCORDING TO THE WATER RESISTANCE

The water immersion test serves as a vital method for evaluating the water resistance of a coating. Factors such as the formulation, thickness of the coating, conditions under which curing is performed, porosity, exposure to the environment, interaction with the substrate, methodologies employed for testing, and parameters all contribute to the variations observed in the results pertaining to water resistance (Zhang et al., 2021). Comprehending these variations empowers those formulating the coatings to develop coatings that maintain their structural integrity and functionality in the face of challenges related to water, thereby ensuring durability and reliability across a multitude of applications. Water resistance variations are shown in Figure 3. After water immersion, test hardness of coatings and again highest hardness coating become T1. T1 and T2 were not significantly differed from each other but they were significantly differed from other seven coatings.

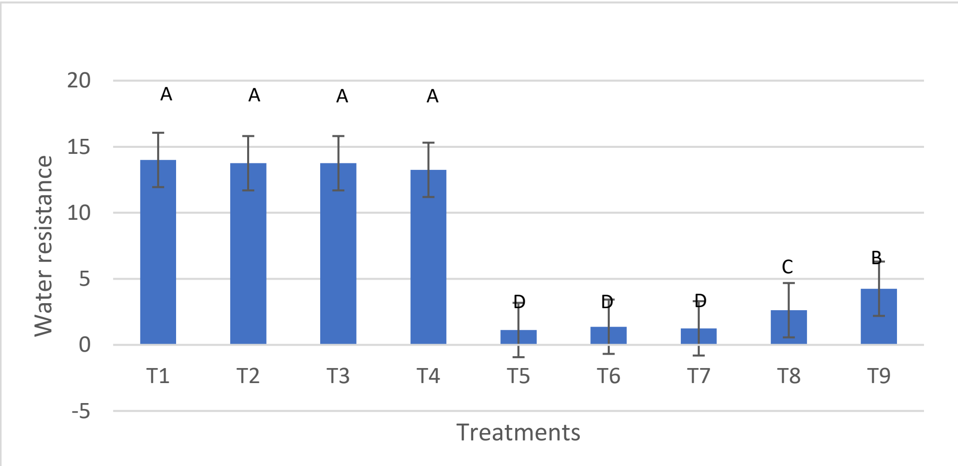

Figure 3: Water resistance vs Treatments

*(*Vertical bars indicate the standard errors of the mean water resistance (n = 3), Means that do not share a same letter are significantly different according to Ducan Multiple Range Test (DMRT))*

4.4 EVALUATION OF PH VALUES

The pH values of coatings significantly impact their formulation, application, adhesion, curing, and overall longevity. To ensure that coatings deliver uniform performance, robust adhesion, and enduring protection under diverse conditions, it is imperative to appropriately consider and regulate pH during both the formulation and application stages. A detailed grasp of how pH affects coatings can aid in the creation of coatings that satisfy certain performance criteria in a variety of applications. The best pH value for coating is 6.5-8.5 (ISO 19396- 2:2017). The pH values of the treatments are shown in Figure 4. Therefore, every treatment needs future developments because any of them not reach that range.

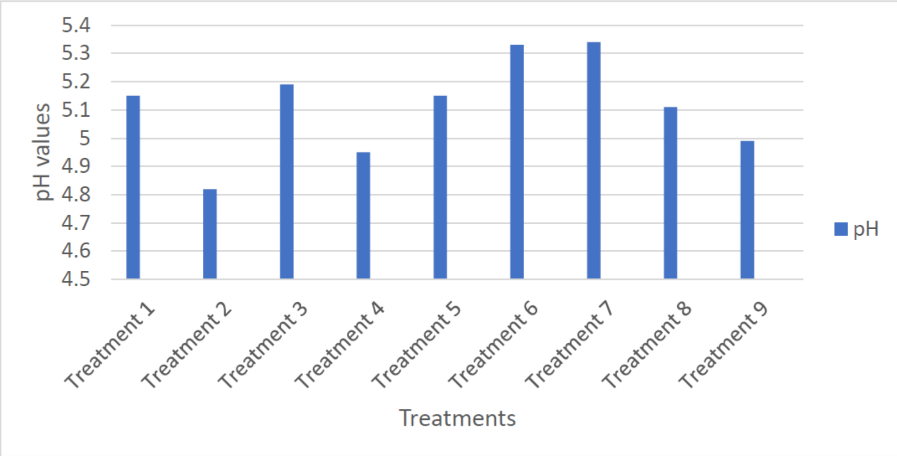

Figure 4: pH vs Treatments

4.5 EVALUATION OF VISCOSITY

The viscosity of wall coatings is a significant element that considerably influences their application, adhesion, film thickness, texture, and overall finish. To ensure uniform application, sufficient adhesion to vertical surfaces, and the desired appearance, it is essential to achieve the correct balance of viscosity (Yuan et al., 2013). Appropriate formulation, viscosity testing, and modifications are vital for wall coatings to meet performance and aesthetic standards across various application conditions. Accepted range viscosity for coatings is 25-35 maps (ISO 2884:1974). The viscosity values are shown in Figure 5. The T1, T2, T3 and T4 were between that range.

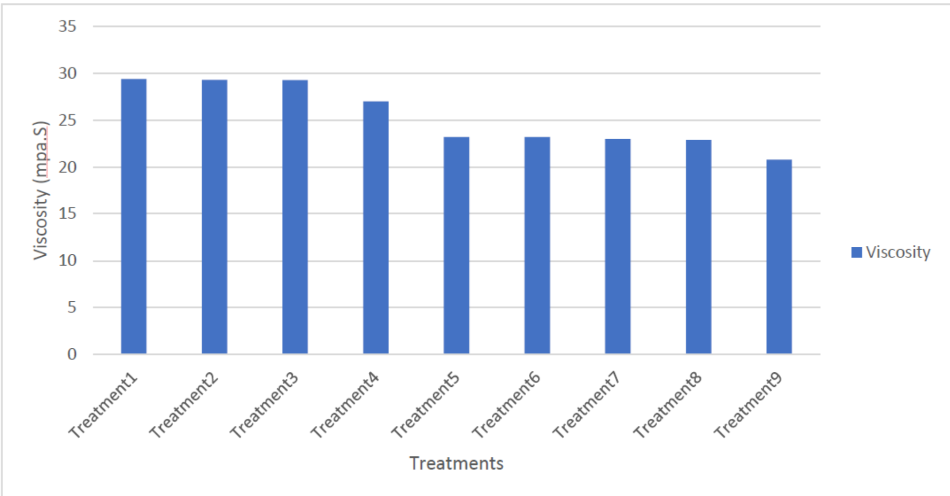

Figure 5: Viscosity vs Treatments

4.6 EVALUATION OF VISUAL APPEARANCE

Beyond basic aesthetics, the visual attractiveness of coatings plays a significant role in influencing product quality, consumer perception, and functional performance. This aspect is particularly pertinent in industries where coatings are crucial for enhancing the aesthetic appeal of various objects and surfaces. Numerous internal and external factors influence the perception of coatings in terms of their visual appearance, collectively impacting the overall impression they create. Color, gloss, and texture are fundamental components of these factors (Barletta et al., 2018). The selection of color serves as a medium for expressing brand identity, aesthetic appeal, and product uniqueness, in addition to personal preference. The final color is determined by additives and pigments, and it can be modified to evoke specific emotions or to fulfil practical requirements. Visual appearances are depicted in Figure 6. Smooth wall surfaces exhibit greater resistance to fungal growth (Udawattha & Halwatura, 2018). Further to the authors, smooth wall surfaces are more resistance to fungi growth. When consider these coatings T1 shows best visual appearance.

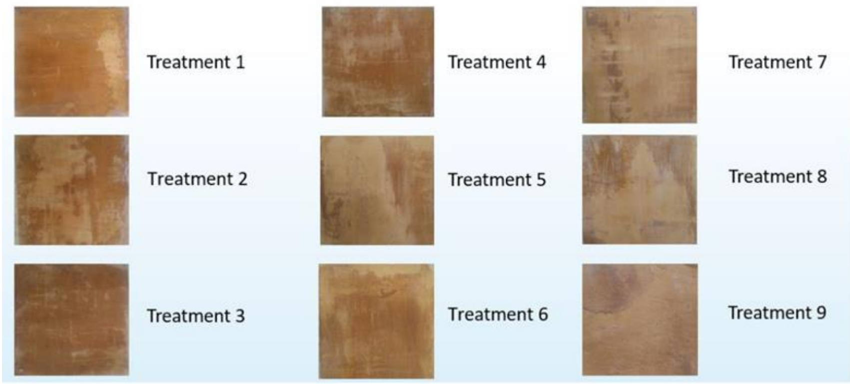

Figure 6: Visual appearance

5. DISCUSSION

This study comprehensively evaluates the multifaceted properties of coatings, emphasising both visual attractiveness and functional performance. Key findings include the significance of pH, viscosity, adhesion, hardness, and water resistance for identifying product performance. Optimal pH levels (6.5-8.5) are crucial for coating formulation, application, and durability, though adjustments were needed to maintain this range. Viscosity, within the standard 25-35 mPas, significantly affects application and adhesion, with T1, T2, T3, and T4 performing best. Adhesion, influenced by substrate, preparation, formulation, and environmental factors, was highest in T1, T2, T6, and T9. Pencil hardness tests identified T1, T2, T3, and T4 as having superior mechanical endurance. Water resistance, essential for coating longevity, showed T1, T2, T3, and T4 as the top performers, though further improvements are possible. Overall, the research underscores meticulous formulation and application methods to achieve high-performance, durable coatings, offering valuable insights for industry advancements and innovation.

Additionally, when comparing the Sigiriya paintings to the Ajanta cave paintings, a specific reason for using an oil medium in the Sri Lankan paintings becomes apparent (Seneviratne, 2020). The majority of Sigiriya paintings are located outdoors, where superior water resistance properties are crucial. This advantage of the oil medium was confirmed by the study's results.

Notably, the coating formulated with in the study demonstrated results that align with ASTM standard for wall coatings. This suggests that there is potential for the development of advanced coatings using methodologies derived from ancient coating technologies. Furthermore, this coating was developed entirely from natural materials, underscoring the feasibility of creating innovative coatings based on traditional practices. Therefore, this experimental study underscores the importance of preserving the intangible cultural heritage of Sri Lanka through the lens of scientific innovation. This endeavour draws inspiration from the rich heritage of Sri Lanka, where ancient artisans possessed profound insights into the chemical interactions within their coatings. Moreover, they ingeniously crafted paintings and coatings to withstand the country's diverse climatic conditions.

6. CONCLUSIONS

The exploration and prototyping of an ancient coating technology from Sigiriya represent an intriguing convergence of historical context and modern materials science. By decoding the composition of the initial coating and formulating a modern equivalent, this study has procured an invaluable understanding of the expertise of ancient craftsmen.

Theoretically, this research enriches the understanding of ancient coating technologies, offering insights into the materials and methods used by ancient Sri Lankan craftsmen. It contributes to the broader field of materials science by demonstrating how historical techniques can inform and enhance modern formulations. Practically, the findings suggest that the modern equivalent of the Sigiriya coating can be effectively used in heritage conservation. The resilience and protective qualities of prototype T1 make it a promising candidate for preserving not only cultural relics but also modern art pieces, ensuring their longevity and durability through further development.

The contemporary prototype T1 exhibits potential in terms of resilience and safeguarding, paving the way for its application in the conservation of cultural relics and modern art pieces. Subsequent research could probe further into the refinement of the formulation for distinct applications and investigate its viability in global heritage preservation initiatives. The heritage of Sigiriya persists not solely in its awe-inspiring paintings but also in the pioneering technologies utilised by its ancient residents. Through endeavours to comprehend and replicate these ancient coatings, this study honours the proficiency of Sri Lankan ancestors while preserving cultural assets for future generations.

The study faced several limitations, including the challenge of precisely replicating ancient materials and methods with available modern equivalents. Additionally, the testing conditions may not fully replicate the environmental factors that the original Sigiriya paintings endured over centuries. The study's scope was also limited to specific formulations and testing methods, which may not encompass all possible variables influencing the coatings' performance.

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