

**Research Paper**

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**Circularity in Concrete Construction: Investigating the Interplay Between Multiple Softwood Formwork Reuse and Varying Workability on Hardened Concrete Properties****Zaheer Doomah<sup>1\*</sup>, Sailesh Kumar Singh Nunkoo<sup>1</sup>, Alvinsing Kokil<sup>2</sup>, Bhavesh Nunkoo<sup>2</sup>**<sup>1</sup> Lecturer, Department of Civil Engineering, University of Mauritius, Reduit, Mauritius<sup>2</sup> Research student, Department of Civil Engineering, University of Mauritius, Reduit, Mauritius**Abstract**

The construction industry accounts for 33% of the global emissions of greenhouse gases and makes use of a whopping 40% of global resources. In addition, statistics reveal that over 10 billion tons of construction waste are produced yearly worldwide. It is therefore essential to promote circular economy principles in this sector to ensure lower wastage of resources and greater sustainability. Along these lines, this study aimed to investigate the possibility of reducing the demand for formwork by studying the effects of reusing pine formwork with differing concrete workability on the properties of hardened concrete. For this purpose, concrete cubes of Grade 35 were cast into four formwork categories, namely steel (control for this study), new pine softwood formwork, pine softwood formwork used once on site, and pine softwood formwork used thrice on site, utilising concrete mixes with varying water-to-cement ratios. Three tests were conducted to investigate the strength and durability of the concrete, namely compressive strength, water absorption, and chloride content penetration. The findings of this study demonstrated that pine softwood formwork has the potential to be reused up to a maximum of three times if utilised with a water-reducing admixture. The results of this study can help to promote circular economy principles in the construction sector by informing engineers and other construction professionals of the potential scenarios for reuse of the softwood formwork and adapting the mix design accordingly, while also developing good site management principles for reducing waste from formwork.

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**Keywords***Circular economy; Softwood formwork; Hardened concrete; Workability; Admixtures.***1. Introduction**

The construction industry is one of the largest consumers of natural resources and waste generators worldwide and is therefore under increasing pressure to address its environmental impacts while improving efficiency (Abuimara et al., 2025; Akanbi et al., 2018; Akhimien et al., 2021; Guerra & Leite, 2021; Khalfan, 2019). Transitioning from a linear economy model promoting single-use of materials to a circular economy model has been touted as a promising strategy for addressing the global sustainability challenges being faced by the construction sector (Charef et al., 2022; Geldermans, 2016). Circularity in construction enables the repurposing and recycling of used and by-product materials, and this provides significant potential for reducing the use of new resources and landfill wastage (Shkirman et al., 2025;

Zeng et al., 2022; Xu et al., 2024). Formwork made of wood, metal, and other materials is widely used in concrete construction to provide support and mould elements into various shapes (Li et al., 2022; Mei et al., 2022), with research showing that this accounts for approximately 25% of the total project costs (Liebringshausen et al., 2023). However, formwork made of timber tends to be considered a single-use material and is discarded as concrete demolition waste after being used once. The circular economy, therefore, provides a sustainable framework for utilising and valorising wood waste from concrete construction sites, while also reducing the need to cut down more trees (De Souza Barros et al., 2025; Mei et al., 2022).

It is well documented that hardened concrete properties, such as strength and durability, are affected by several factors, including cement characteristics, aggregate types, water-to-cement ratio, admixture properties, mixing time, temperature, and the production process (Demissew, 2022). Amongst these, the water-to-cement ratio also plays an important role in the workability of fresh concrete, which refers to the ease with which concrete can be mixed, placed, compacted, and finished while remaining homogeneous (Ahmad et al., 2022). Varying levels of workability, or slump, are used depending on the nature of the construction component, with higher slumps used in structures with congested reinforcement and lower slumps for more conventional concrete applications (Neville, 2017). However, the higher water-to-cement ratios needed for greater workability also lead to a reduction in the strength and durability of concrete (Piasta & Zarzycki, 2017; Yang et al., 2021). Admixtures have been used successfully to improve the fluidity of concrete and thus reduce the water-to-cement content, thereby improving hardened concrete properties (Altun et al., 2020; Bukhari & Moradillo, 2025; Zhang, 2018).

Existing research has established the significance of the formwork in producing concrete with good characteristics, and that reused formwork can negatively impact the properties of hardened concrete (Jiang et al., 2025; Rubarutuka, 2013). However, there has been little research on the potential to mitigate this adverse impact through the use of admixtures such as plasticisers and water reducers, which are commonly used to improve concrete workability without adding extra water (Lokesh et al., 2023; Yang et al., 2024). Understanding the interplay between reused formwork and the use of admixtures is therefore essential, as this will provide much-needed insight into the characteristics of resulting concrete and can lead to a greater adoption of reused formwork on construction sites. This study, therefore, aims to investigate the combined effects of workability variation and formwork reuse on the properties of hardened concrete. By addressing this critical gap, the research seeks to advance sustainable and durable construction practices, contributing to a more resilient built environment, particularly in regions like Mauritius, where coastal infrastructure is increasingly vulnerable to climate change and saline conditions.

### **1.1. Reuse of formwork materials**

Modern concrete construction uses various types of formwork made from different materials: timber, plywood, steel, aluminium, and plastic, with each having its own advantages and disadvantages in terms of cost, durability, flexibility, and environmental impact (Das et al., 2016; Devi & Yadav, 2023). Formwork selection can also have a major impact on the surface quality and finish of concrete being cast, as well as its strength development and durability (Nilimaa et al., 2023; Terzioglu et al., 2021). With the need to reduce material usage and adopt circular economy principles, more emphasis has been laid recently on reusable formwork that can be removed after use, cleaned, and used again (Gappmaier et al., 2024). Thus, several studies have been carried out to assess the potential of formwork reuse and have shown that, despite its vulnerabilities, timber and wooden formworks have good potential for being recycled and reused on construction sites. These are briefly summarised below:

A study by Mukhopadhyay et al. (2022) on the resizing and reuse of construction materials identified several advantages of the reuse of timber formwork. The benefits included ease of management and handling of the used timber formwork materials for reuse, the cost efficiency achieved through reduced material usage, and improved waste generation control.

In their review study on formwork systems, Li et al. (2022) carried out a comparison of several materials, including wooden, metal, fabric, and 3D-printed plastic formwork. They posited that although the material cost for wooden formwork is lower than for metal formwork, they have higher labour costs and offer only a medium quality surface finish. However, the wooden formwork can be used for a range of shapes, including complex geometries, and can also be recycled and reused.

Pronk et al. (2022) adopted a case study approach to assess the potential for reuse of wooden formwork through the use of 10 construction projects. They found that although large amounts of timber formwork are used, their reuse is still limited, with the maximum number of use cycles as formwork being determined by the roughness of the formwork and the project characteristics. The authors eventually posited that although timber formwork may not be reused for elements that are visible and need to be aesthetically pleasing, they offer vast potential for other purposes, as they still possess good mechanical properties. However, the study also pointed out that several challenges need to be overcome for mainstreaming material reuse, as although waste and cost reduction can be achieved by using reclaimed materials, the design and construction process is rendered more complex and can increase the total project budget owing to additional logistics and planning issues.

Using a mathematical modelling approach, Mei et al. (2022) argued that reusing formwork among several construction sites led to a reduction of the total cost across the whole supply chain while improving sustainability. They further posited that the reuse of materials could also prevent the underutilisation of undesired materials through the development of detailed material planning and hence lead to a significant reduction in the construction schedule as well.

Cheng et al. (2022) elaborated on the reuse of timber formworks for traditional in-situ concrete casting. They discussed the actual use of this type of formwork, which is usually purchased in standard sizes before being processed according to the design and construction requirements, thus generating waste. Moreover, with construction schedule requirements, several sets of timber formwork are required to prevent delays, leading to a surplus of materials on the site. The authors also posited that the reuse of timber formwork is limited to 3 – 8 times before being discarded due to large deformations and significant material accumulation on the surface.

## **1.2. Impacts of formwork materials on concrete properties**

There has only been sparse research on the impacts of the reuse of wooden formwork on concrete properties, with the few studies summarised below:

Jiang et al. (2025) investigated the impact of the choice of three formwork materials (plastic, plywood, and steel) on the aesthetic properties of concrete surfaces and found that the number and frequency of bugholes were highest for steel formwork, while minimal for the plastic one. Moreover, in terms of concrete surface roughness, the highest values were obtained for plywood, followed by steel and lastly plastic, and this mirrored the increasing formwork roughness closely after several reuses of these materials. It was also determined that while the appearance of concrete made using the different formworks was similar initially, larger than 10 times plywood formwork reuse led to a significant concrete colour difference. The authors finally concluded that the quality of concrete decreases with increasing reuse, depending on the formwork material, with the plastic formwork being mainly subject to physical damage due to friction and paste adhesion, while the plywood and metal formworks suffered from both physical and chemical damage, mainly as a result of alkali corrosion. The study also posited that increasing the reuse of plywood formwork led to a dusting phenomenon on its surface, which increased air void defects and roughness of the concrete surface, leading to poor-quality concrete.

In another study to evaluate the impacts of formwork materials on the sorptivity of concrete cover and the durability of concrete, Aïssoun et al. (2017) compared plywood and PVC formworks, with the former being rougher and more absorbent. They observed that while the smooth and non-absorbent PVC formwork did not have any major impact on the rheological properties of fresh concrete, the rough and absorbent plywood surface led to a reduction in the water-to-cement (w/c) ratio and fluidity of the cement paste. They also noted that the wall effect, i.e., the movement of coarse aggregates near the formwork surface, was greater for plywood due to the increased water absorption and surface roughness, leading to a decrease in movement of coarse aggregates near the surface and therefore a higher packing density. Thus, concrete cast in plywood formwork had lower sorptivity of concrete cover and ultimately higher durability.

Earlier research by Rubaratuka (2013) found that the use of absorbent formwork materials had a beneficial effect on concrete surface properties, with an increase in concrete strength and hence durability. The author compared 4 types of materials, namely softwood timber, hardwood timber, plywood, and steel, and concluded that concrete compressive strength was highest for the softwood and plywood formwork and lowest for the steel formwork. This was explained

by the fact that softwood formwork had the greatest water absorption and thus allowed greater dissipation of water and entrapped air that migrated to the interface of concrete and formwork.

### 1.3. Impacts of water-reducing admixtures on concrete properties

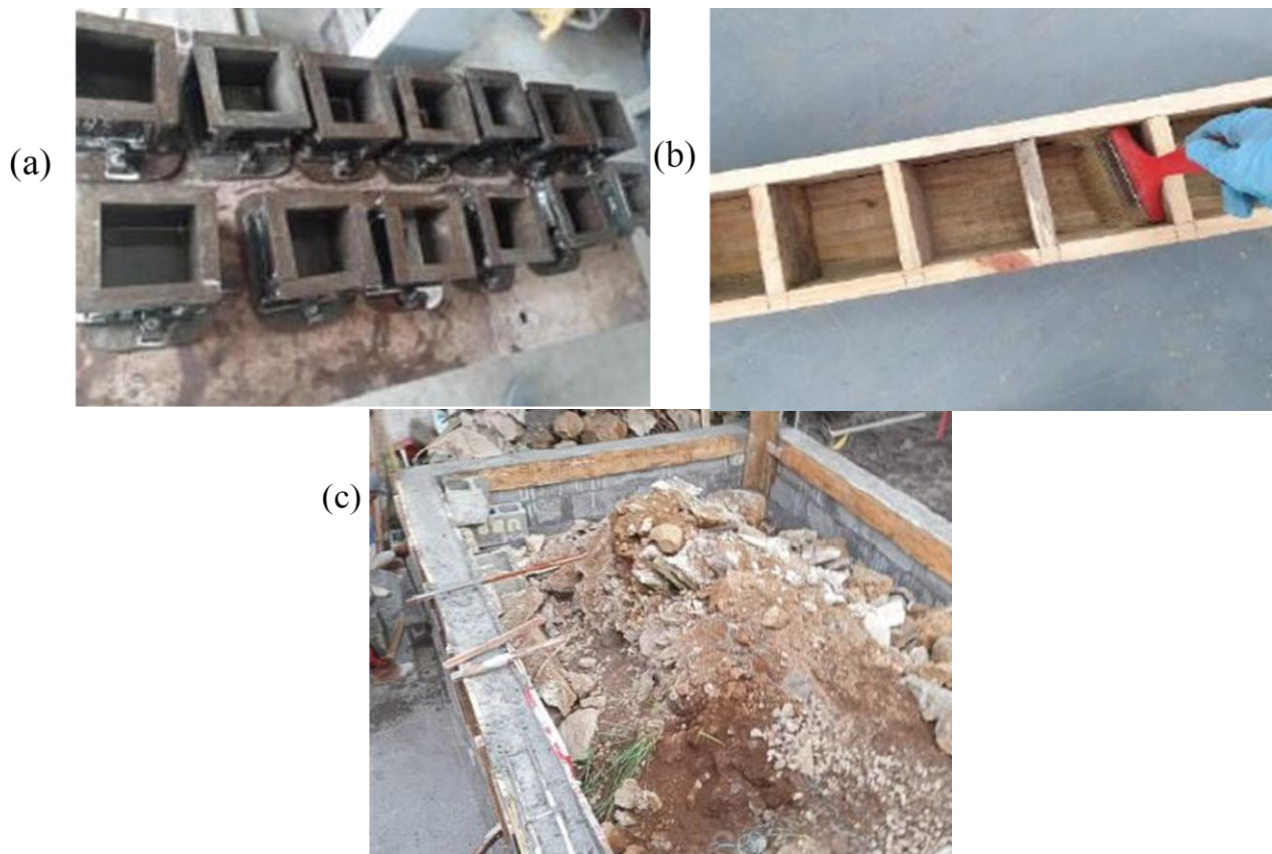
The mechanism of action and impacts of water-reducing admixtures on concrete properties are well documented in the literature. This type of admixture allows for a reduction in the water content and thus a lower w/c without decreasing the workability and the slump range required, thereby leading to concrete mixes achieving higher strength, density, and durability (Bukhari & Moradillo, 2025). Moreover, using admixtures allows achieving the required concrete grade with lower cement content while also making the task of concrete placement easier in difficult site conditions. Conventional water-reducing admixtures allow for a reduction in the water content by at least 5% and thus allow for densely packed cement grains for higher durability (Lokesh et al., 2023).

## 2. Methodology

This section discusses the materials and the test methods used for the study.

### 2.1. Materials

In Mauritius, pine timber formwork is widely used due to its versatility and local availability, especially in residential and small-scale projects. Traditionally treated as a single-use material, timber formwork contributes significantly to waste and environmental degradation. Therefore, for this study, pine timber formwork has been used. Three categories of formwork were considered: new formwork, formwork used once (1<sup>st</sup> use formwork), and formwork already used three times (3<sup>rd</sup> use formwork). These formworks were all obtained from the same site to ensure they all experienced the same working conditions in terms of weather and handling. Steel moulds were used as the control for comparing the results obtained. Pictures of the formworks used are shown in **Figure 1** below.



**Figure 1.** (a) Steel moulds, (b) New formwork, (c) Used formwork from the site.

The other materials used were also adopted based on usual site practices to prepare the different mixes of concrete considered in the research: Ordinary Portland Cement (CEM II 42.5), fine aggregates (0-4 mm), coarse aggregates (6-

10 mm, 10-14 mm, and 14- 20 mm), and tap water. A liquid water-reducing concrete admixture was used in this case, namely Sika Plastiment R.

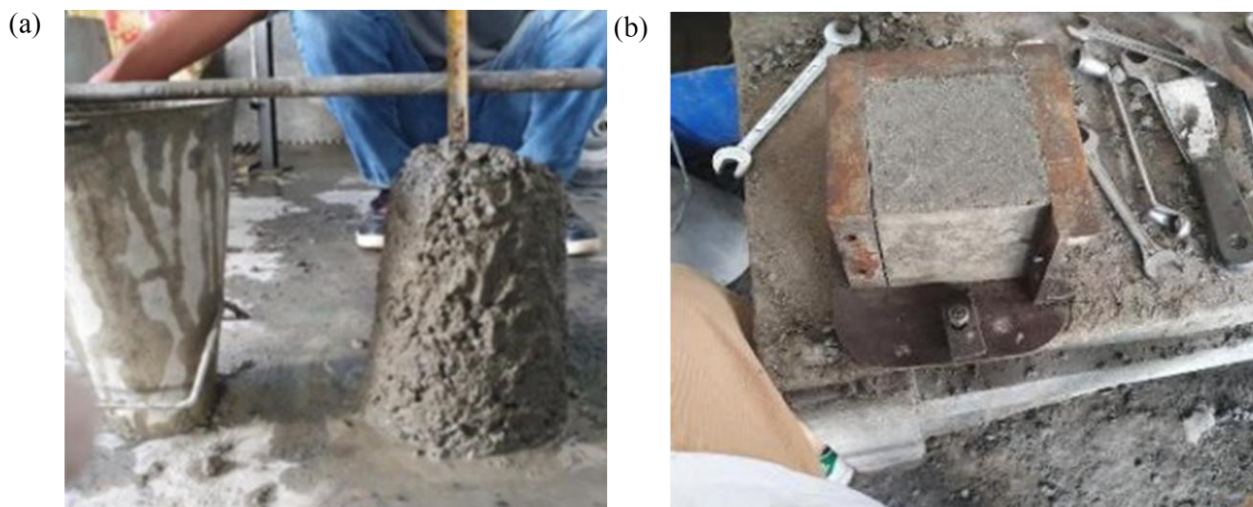
## 2.2. Concrete sample preparation

Concrete Grade 35 was used for this study, with 3 different mixes considered, each having different slumps. Mix 1 consisted of concrete with a slump of 30-60mm, while both Mix 2 and Mix 3 were designed for a 60-180 slump, with the difference that Mix 3's slump was achieved with the use of an admixture and reduced water content. The BRE method (Building Research Establishment, 1988) was used to design the concrete mixes, and a mix proportion of 1:1:1 was used for the coarse aggregate (6- 10 mm, 10-14 mm, and 14- 20 mm). In total, 144 cubes of 100x100x100mm were cast, which included samples for the steel control. The casting was carried out based on BS 1881:Part 125:1983 (British Standards Institution, 1983a). Table 1 shows a summary of the composition of the different mixes for 1m<sup>3</sup> of concrete. The slump was verified after casting using the slump test in accordance with BS 1881: Part 102:1983 (British Standards Institution, 1983b) procedures.

**Table 1.** Concrete mix design.

Concrete Mix	Mix 1	Mix 2	Mix 3
Cement strength class	42.5	42.5	42.5
Cement (kg/m <sup>3</sup> )	385	410	385
Water (kg/m <sup>3</sup> )	260	275	226
Fine aggregate (kg/m <sup>3</sup> )	760	840	760
Total Coarse aggregate (kg/m <sup>3</sup> )	1050	915	1050
Admixture (cc/100kg cement)	-	-	300

**Figure 2** illustrates the slump test and demoulding of the cubes for curing and testing. Curing was done according to normal BS test procedures, with the cubes demoulded and immersed completely in a water tank until testing.



**Figure 2.** (a): Slump test, (b) Demoulding of concrete cube.

For this study, 3 tests were considered, namely the compressive strength test, the water absorption test, and the chloride content test. All these tests were carried out as per the standards, as shown in **Table 2** below. The tests were performed after allowing the samples to cure for 7 and 28 days at room temperature.

**Table 2.** Test standards used for concrete testing.

Test Performed	Standards
Compressive Strength	BS EN 12390-3:2019 (British Standards Institution, 2019)
Water Absorption	BS 1881-122:1984 (British Standards Institution, 1983e)
Chlorine ion content	BS1881-124:1988 (British Standards Institution, 1988)

### 3. Results

This section discusses the results obtained from the tests carried out on the concrete samples.

#### 3.1. Concrete compressive strength

The test was performed based on BS-EN 12390-3:2019. The test was carried out on the 7th and 28th day on compressive strength. Three individual samples were used for all compressive strength tests carried out. The results are illustrated in **Figure 3**. A total of 144 cubes were cast: 36 cubes were cast for each mould type, with 12 for each of the 3 mixes to be used as follows: 3 for 7th day compressive testing, 3 for 28th day testing, 3 for water absorption test, and another 3 for chloride testing. Each test was hence replicated 3 times. The mean values of the concrete compressive strengths were calculated and used for each mix and formwork type. It was noted that for all mixes, standard deviation values were less than 5.0 MPa, as recommended by BS-EN 12390-3:2019, thus indicating good quality concrete.

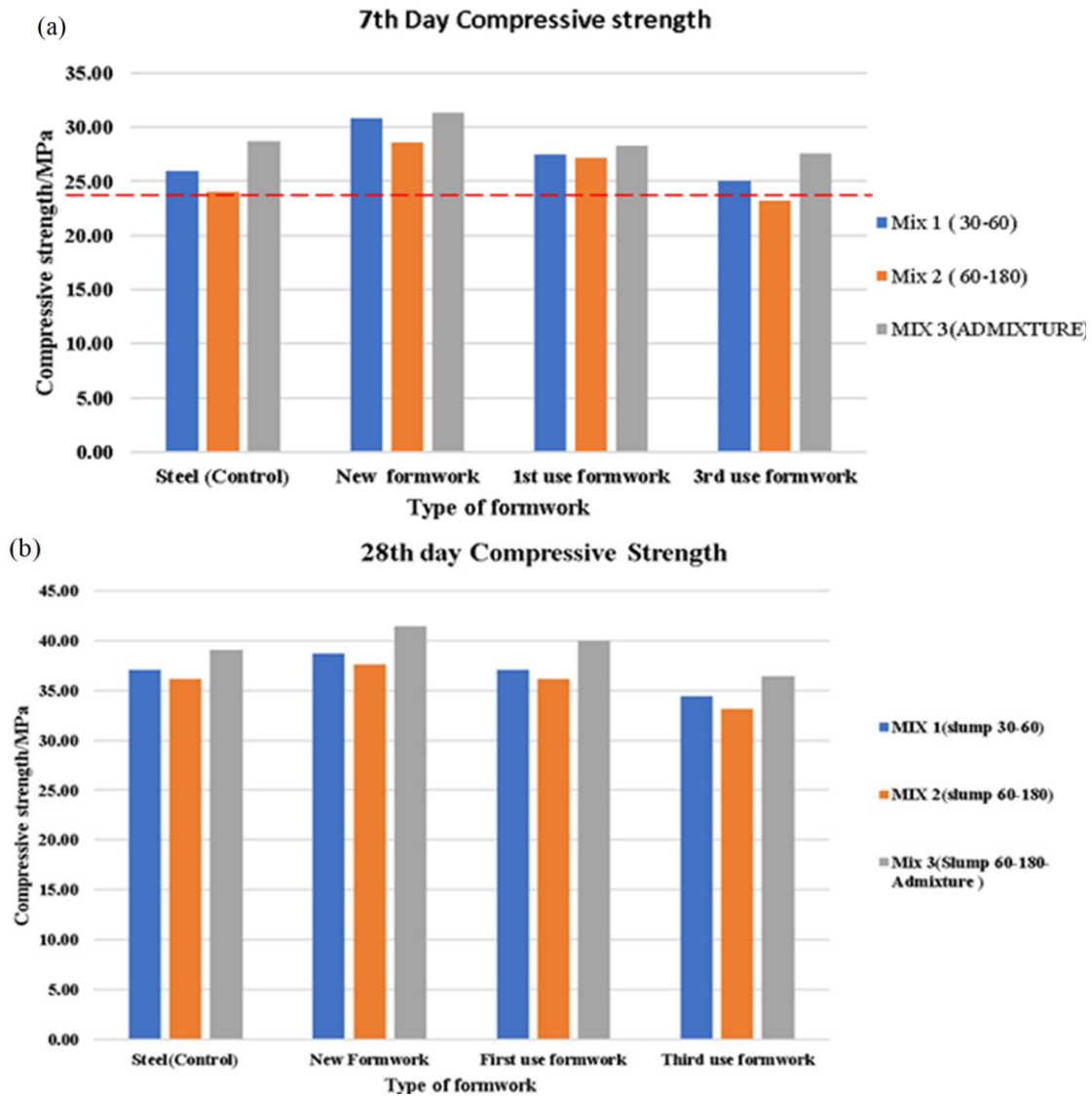


Figure 3. (a) 7<sup>th</sup> day compressive strength, (b) 28th day compressive strength.

For the 7th day, the compressive strength should have reached two-thirds of its designed strength, as stated by Weru (2018). From the graph above, it can be observed that only the combination of Mix 2 and the third use of formwork failed to achieve this target. Testing for the 28th day compressive strength indicated that concrete cubes cast in formwork, already used once, performed satisfactorily.

However, for the formwork already used thrice, both Mixes 1 and 2 cubes failed to achieve the targeted strength. This can be explained by the changes in the formwork surface caused by the successive pouring-hardening-demoulding cycles that lead to the adherence of cement paste to the surface and thus clogging of pores, protrusions, and raising of fibres (Jiang et al., 2025). Moreover, this also leads to greater friction during demoulding, which can create microcracks in the concrete. However, the cubes made use of the admixture to meet the design characteristic strength of 35MPa. This can be explained by the reduced water content in this mix, which helped to mitigate the negative effects due to the degradation of the formwork as a result of several uses. This constitutes an important finding as it shows the efficiency of the admixture in achieving the required target strength while also demonstrating the need to shift from the usual procedure of increasing concrete workability through the addition of water in the mixture, as this is incompatible with circular formwork reuse.

### 3.2. Water absorption

The results shown in **Figure 4** indicate that the water content in the concrete design mix has an effect on the water absorption of concrete for all the types of formwork considered. Mix 1 produced concrete with lower water absorption

compared to Mix 2 for all formwork categories. However, Mix 3 with admixture use and reduced water content yielded the lowest water absorption for all formwork categories. Moreover, for the third use of formwork, the water absorption was in a similar range to that of the steel moulds, while those for new and first-time formwork had lower water absorption.

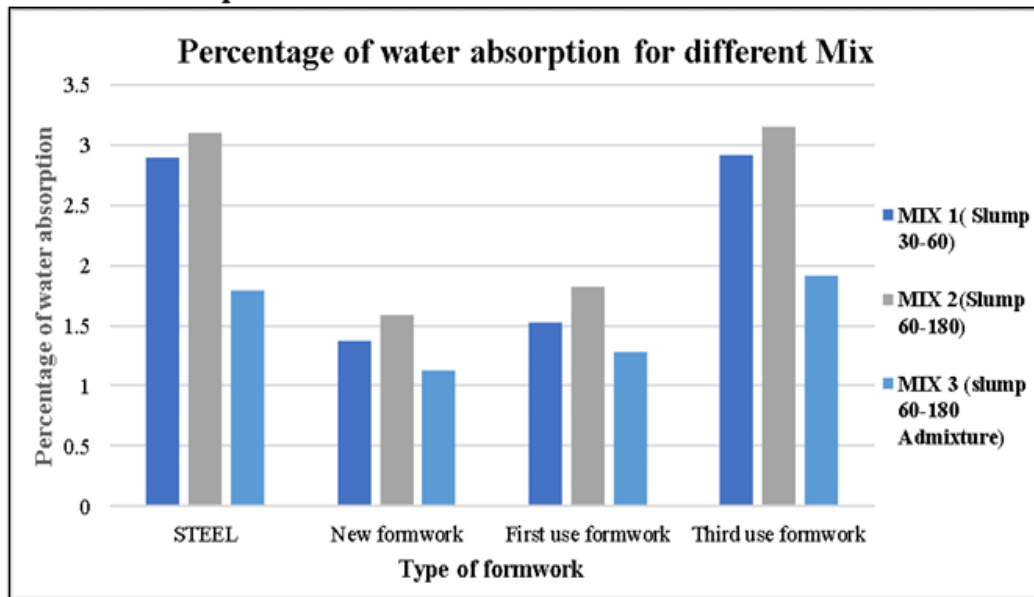


Figure 4. Water absorption of concrete specimens.

### 3.3. Chloride ion content

Figure 5, Figure 6, and Figure 7 indicate that the chlorine content decreased with increasing depth for all mixes. New formwork was seen to consistently produce concrete with the lowest chlorine ingress content, followed by first use and then third use, due to the ability of new formwork to absorb water from the mix, allowing concrete to have a lower w/c ratio. Mix 3 and new formwork produce the concrete with less chloride ion ingress due to the combined effect of a lower w/c ratio and the reduced voids, as shown in Figure 8. Mix 2 and third use formwork (at a depth of 30-50mm) was observed to produce the highest chloride content in the concrete due to the increased voids, as shown in Figure 8. This is particularly a concerning factor as reinforcements are usually placed at this depth for structural elements. Lastly, it was noted that for Mix 3, the chloride levels were maintained within the corrosion threshold of 30 – 50mm for the various types of formwork used, whereas for Mix 2, this was not achieved for the third-use formwork.

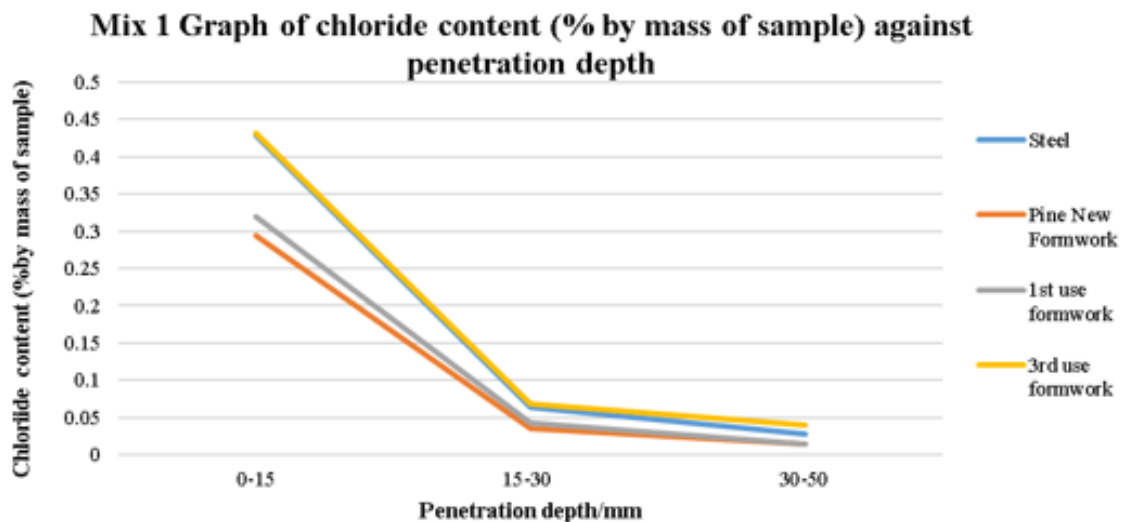


Figure 5. Chloride content for Mix 1.

**Mix 2 Graph of chloride content (% by mass of sample) against penetration depth**

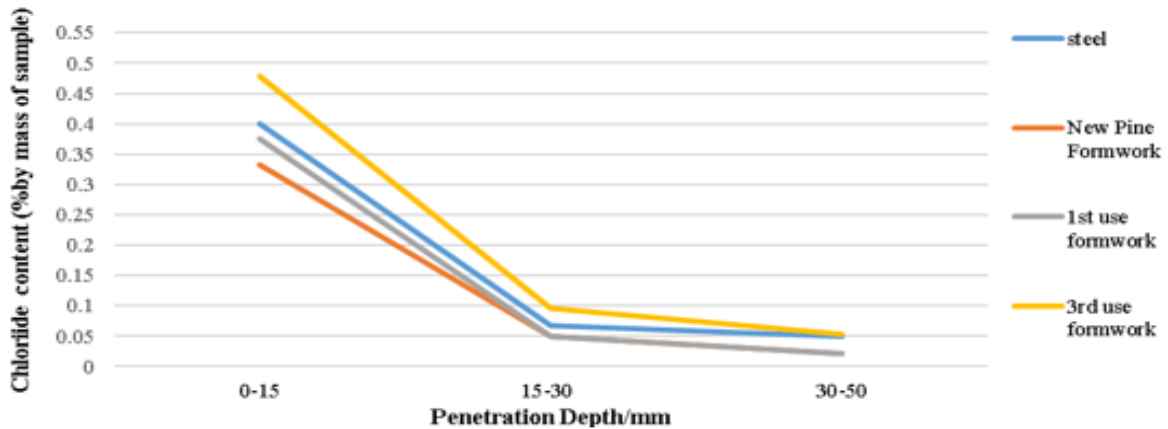


Figure 6. Chloride content for Mix 2.

**Mix 3 Graph of chloride content (% by mass of sample) against penetration depth**

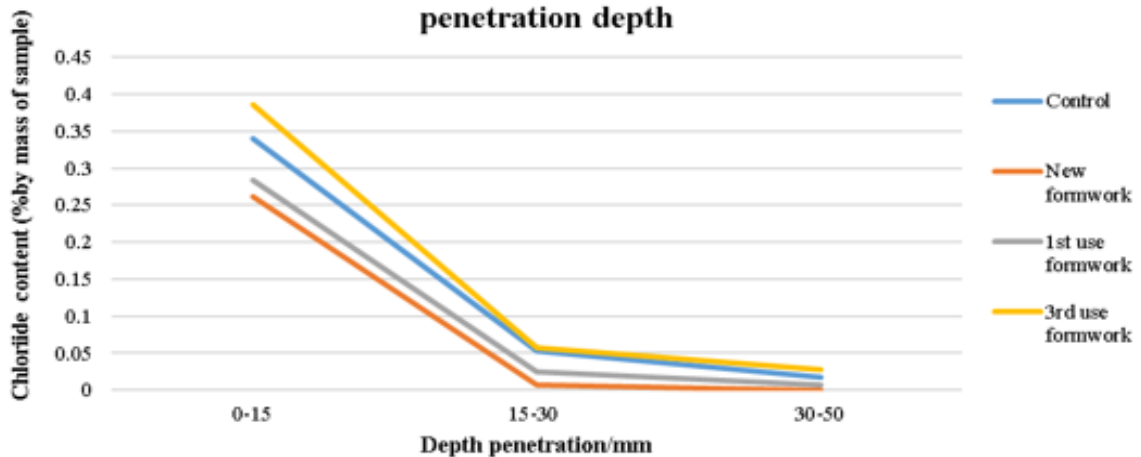


Figure 7. Chloride content for Mix 3.

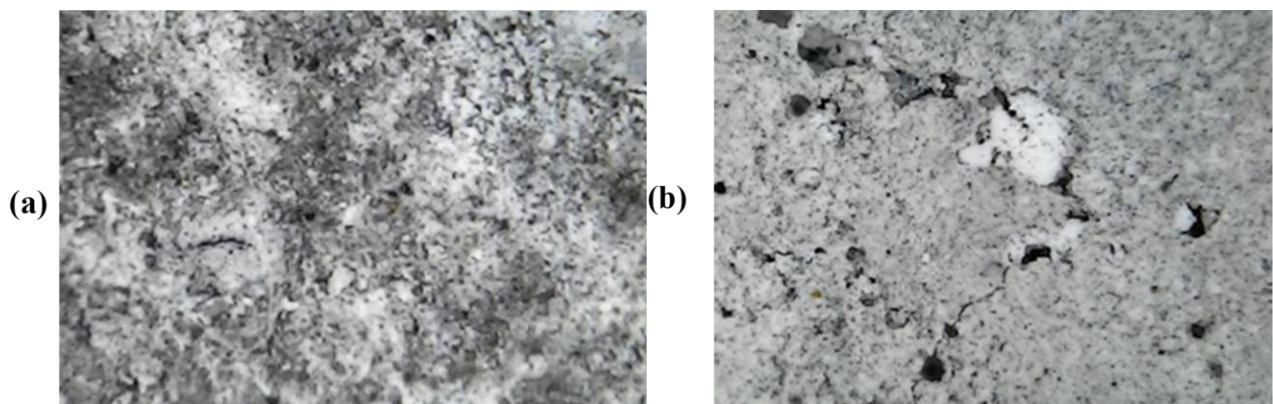


Figure 8. (a) Concrete from mix 3 and new formwork, (b) Concrete from mix 2 and 3<sup>rd</sup> use formwork.

#### 4. Discussion

The study set out to assess the impacts of slump variation (through water-to-cement ratio variation and admixture use) and softwood formwork reuse on the properties of hardened concrete. Findings for new formwork, formwork used once, and thrice were compared with the control in the form of steel formwork to assess the suitability of timber formwork reuse for concrete construction. The main limitation of this research was the number of replications for each mix type

and formwork, with only 3 similar tests carried out for each scenario. However, possible errors due to this shortcoming have been curtailed by adopting stringent quality control procedures as recommended by the relevant British Standards. Moreover, only pine formwork has been investigated in this study, and this can be further expanded to other types of timber used as formwork in the construction industry.

In terms of compressive strength, positive results were obtained for formwork used once for all mixes, with no significant decrease compared to results obtained for new timber formwork. This may be explained by the fact that the voids in the formwork have not been blocked significantly and still allow water to be absorbed (Dapper et al., 2024). However, for softwood formwork, which had already been used thrice, only the mix using admixture performed satisfactorily due to the reduction in water-to-cement ratio. The findings indicate that while softwood formwork may be reused at least once, more care needs to be exercised when considering reuse more than two times, as the degradation in formwork may lead to lower compressive strength. However, the use of water-reducing admixtures may help to overcome this issue and thus allow further reuse of softwood formwork.

In terms of water absorption, it was noted that the lower the initial water content, the less the water absorption of the concrete specimens for normal mixes, in line with previous studies (Piasta & Zarzycki, 2017; Yang et al., 2021). However, the mix with the admixture outperformed the others and yielded the lowest water absorption for all formwork categories. This is in line with findings from Lokesh et al. (2023), who found that the use of water-reducing admixtures helps to reduce the number of cracks by minimising water loss from the concrete. This is particularly crucial for this study as it shows that the concrete produced with used softwood formwork performs satisfactorily in terms of water absorption when combined with water-reducing admixtures.

Lastly, results indicated that new softwood formwork produced concrete with the lowest chlorine ingress content, followed by first use and then third use, due to the decreasing ability of formwork to absorb water from the mix with the number of reuses. Moreover, Mix 3 with the admixture and new formwork yielded the best results with the lowest chloride ion ingress. Finally, to ensure circularity, once the pine has reached its end-of-life for formwork use, it can be repurposed through chipping for secondary applications in various domains, such as providing soft surfaces in walking trails and for weed control in landscaped areas.

While the results have shown the potential for pine formwork reuse, further research, however, needs to be carried out in terms of quantifying the circularity potential in terms of measurable indicators such as onsite waste reduction, decrease in the costs of formwork, percentage of formwork that is being repurposed, and reduction in environmental impacts. These findings can help to promote a wider adoption of circular economy principles in the construction sector.

## **5. Conclusion**

The findings of this study have addressed the research question set at the beginning of this study by elucidating the impacts of combined reuse of softwood formwork and varying workability on important properties of hardened concrete. Useful insights have been obtained on the potential of admixtures to improve the characteristics of concrete being cast in softwood formwork that had been previously used. The results have shown that pine softwood formwork can be safely reused once for concrete construction, but more care should be exercised if the formwork is being reused more than once. However, the use of water reducers has shown great potential to mitigate the negative effects on the properties of concrete in terms of compressive strength, water absorption, and chloride ion ingress, with concrete specimens performing satisfactorily even for formwork having been used thrice. This may be particularly useful when carrying out concrete works with marine exposure, which is frequent in Small Island Developing States like Mauritius. By highlighting the strategic use of water reducers to mitigate the adverse effects of reuse formwork, this study has also offered encouragement for greater adoption of the practice of reuse of softwood formwork, inducing a reduction in waste and carbon footprint, thus contributing to promoting environmentally friendly practices.

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### Ethics approval

Not applicable.

### Conflict of interest

The authors declare that there is no competing interest.

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