

Laboratory study on the effect of adding tea powder additive on the compressive strength and shear bond strength of drilling cement

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ABSTRACT

Well cementing provides zonal isolation and structural support, evaluated via compressive strength (CS) and shear bond strength (SBS). This study aims to analyze the effect of adding tea powder waste (0%, 1%, 2%, 3%, and 4%) as an organic additive (retarder and filler) in Class G drilling cement. Standard and modified cement samples were cured in a water bath prior to strength testing. Results showed that tea powder continuously decreased CS as concentration increased, with the highest value at 0% (372.52 psi) and the lowest at 4% (15.52 psi) due to delayed setting time and increased porosity. Conversely, SBS exhibited a fluctuating trend, peaking at 1% concentration with 1,102.13 psi (up from 734.75 psi at 0%) before dropping to 293.90 psi at 4%. In conclusion, the optimum concentration of tea powder ranges from 0% to 1%, yielding the best combination of compressive and surface bond strength.



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INTRODUCTION

Cementing is a crucial stage in oil, gas, and geothermal well drilling operations. Its primary functions are to provide zonal isolation, protect the casing from corrosion, and offer structural support to the well assembly (Smith, 1990). One of the most important physical parameters for evaluating the success of cementing is compressive strength. The cement must be capable of withstanding hydrostatic and mechanical loads from the formation to ensure the well's integrity is maintained throughout its production life (Nelson & Guillot, 2021).

However, under certain field conditions, standard Class G cement often requires modification to achieve optimal performance. The use of synthetic chemical additives—such as retarders or accelerators—frequently faces challenges related to high costs and adverse environmental impacts. Consequently, current research trends are shifting toward the utilization of organic materials and biomass waste as eco-friendly and cost-effective alternative additives (Martha et al., 2015).

Tea powder contains polyphenolic compounds, particularly tannins and catechins, which chemically have the potential to interact with the cement hydration process. Previous research has shown that organic compounds in plant waste can act as both a retarder and a filler in the cement matrix (Huda et al., 2018). According to a study by Bagus (2015), the addition of tannin-based organic material can influence the microstructure of cement; at certain concentrations, it can reduce density and ultimate compressive strength following the hardening process.

This study was conducted to evaluate the effect of adding tea powder on the compressive strength and shear bond strength of API Class G oil well cement through laboratory testing, thereby determining its effectiveness as an alternative additive for oil and gas well cementing operations.

How does the addition of tea powder affect the compressive strength and shear bond strength of Class G drilling cement?

Does the addition of tea powder significantly improve the compressive strength and shear bond strength of drilling cement?

The objectives of this study are as follows: To determine the effect of adding tea powder at concentrations of 0%, 1%, 2%, 3%, and 4% on the compressive strength and shear bond strength characteristics of drilling cement. To determine the effectiveness of tea powder as a natural additive in controlling the hardening rate and the attainment of optimal compressive strength in drilling cement compared to standard cement (without additives).

This research aims to provide a comprehensive understanding of the influence of the organic content of tea powder on the compressive strength and shear bond strength of oil well cement. Beyond contributing to the academic literature on the development of alternative additives, the use of tea powder offers an innovation in eco-friendly materials ("green additives") that is also cost-effective. This holds practical potential for enhancing the quality and efficiency of oil and gas well cementing operations in the future.

RESEARCH METHODS

This study is a controlled laboratory experiment designed to determine the effect of adding tea powder as an additive on the compressive strength and shear bond strength of API Class G oil well cement. The entire research process was conducted at the STT Migas Balikpapan laboratory. Primary data were obtained through laboratory testing, while supporting information was collected from scientific journals, books, and relevant standards related to oil well cementing.

API Class G oil well cement, tea powder, and distilled water were used as the primary materials in this study (American Petroleum Institute, 2002). Five cement slurry formulations were prepared by varying the tea powder concentration at 0%, 1%, 2%, 3%, and 4% by weight of cement (BWOC). Each specimen consisted of 350 g of API Class G cement and 154 mL of distilled water, while the amount of sodium chloride was adjusted according to the predetermined concentrations. The composition of each cement slurry is presented in Table 1.

Table 1 Cement Slurry Composition

No	Tea Powder Concentration (% BWOC)	API Class G Cement (g)	Tea Powder (g)	Water (mL)
1	0%	350	0.0	154
2	1%	350	3.5	154
3	2%	350	7.0	154
4	3%	350	10.5	154
5	4%	350	14.0	154

Preparation of Base Cement Slurry and Cement Slurry with Additives: The process begins with the preparation of a cement slurry without additives to serve as a control sample. Subsequently, cement slurries are prepared by adding tea powder at predetermined concentration variations until a homogeneous mixture is obtained. **Preparation of Hardened Cement Sample Molds:** The homogeneous cement slurry is poured into cube molds for compressive strength testing and into cylinder molds fitted with casing pipes for shear bond testing. All molds are then sealed and labeled according to the sample variations. **Cement Slurry Curing:** Cement samples were cured by immersion in a water bath at 60°C for 24 hours to ensure optimal hydration and hardening (Wastu, 2023).

After the curing period, the specimens were removed from the molds and tested using a hydraulic press. The applied compressive load was gradually increased until specimen failure occurred, and the maximum load was recorded. The hydraulic press readings, expressed in US tons, were converted into pounds (lb), after which the compressive strength values were calculated in pounds per square inch (psi). The compressive strength calculation considered the specimen dimensions, bearing block area, loading area, and correction factor (K) determined from the height-to-diameter ratio using linear interpolation when necessary, following the calculation procedure applied in this study.

RESULTS AND DISCUSSION

This study examines compressive strength and shear bond strength as influenced by tea powder additives. It employs varying concentrations of the tea powder additive—0%, 1%, 2%, 3%, and 4%—to analyze their effects on compressive strength and shear bond strength.

Tabel 2 Compressive Strength

Cement Slurry Composition	Compressive Strength (psi)
Class G cement + 0% Tea Powder	372,52
Class G cement + 1% Tea Powder	310,43
Class G cement + 2% Tea Powder	153,40
Class G cement + 3% Tea Powder	61,36
Class G cement + 4% Tea Powder	15,52

The base cement without additives (0%) recorded the highest compressive strength, at 372.52 psi. The incorporation of tea powder into the cement suspension was shown to reduce this compressive strength. Higher additive concentrations resulted in a further decline in strength. Specifically, the sample with 1% tea powder saw its strength drop to 310.43 psi. This downward trend continued at levels of 2% (153.40 psi) and 3% (61.36 psi), reaching a low of 15.52 psi when the additive dosage reached 4% (Huda et al., 2018).

Tabel 3 Shear Bond Strength

Cement Slurry Composition	Shear Bond Strength (psi)
Class G cement + 0% Tea Powder	734,75
Class G cement + 1% Tea Powder	1.102,13
Class G cement + 2% Tea Powder	881,70
Class G cement + 3% Tea Powder	367,37
Class G cement + 4% Tea Powder	293,90

A base cement suspension without additives (0%) exhibits a shear bond strength of 734.75 psi. The use of tea powder was found to influence this mechanical parameter. Peak bonding performance was achieved at a 1% concentration, where the value surged to 1,102.13 psi. However, a downward trend in strength emerged as the additive dosage was further increased. Specifically, cement samples formulated with 2%, 3%, and 4% tea powder showed a decline in shear bond strength to 881.70 psi and 367.37 psi, respectively, eventually reaching a low of 293.90 psi.

Picture

To provide a clearer representation of this behavior, the variation in compressive strength and Shear Bond Strength with increasing Tea Powder concentration is illustrated in Figure 1, which facilitates further interpretation of the observed trend.



Picture 1 Effect of Tea Powder on the Compressive Strength and Shear Bond Strength of API Class G Oil Well Cement

Testing of compressive strength and shear bond strength on the base cement (0%) without the addition of the Tea Powder additive yielded a compressive strength of 372.52 psi and a shear bond strength of 734.75 psi. With the addition of the additive at a 1% concentration, compressive strength decreased to 310.43 psi, whereas shear bond strength increased to 1,102.13 psi. This indicates that at low concentrations, Tea Powder is not yet capable of optimally enhancing compressive strength but does contribute to improved interfacial bonding. At a 2% concentration, compressive strength dropped to 153.40 psi, and shear bond strength fell to 881.70 psi.

This demonstrates that adding Tea Powder at specific concentrations can effectively reduce the strength of the cement paste. At a 3% concentration, a significant decline occurred in both parameters: compressive strength fell to 61.36 psi and shear bond strength to 367.37 psi. This reduction is attributed to the composition's integrity beginning to affect the cement's internal structure, resulting in lower strength. With a 4% additive addition, compressive strength decreased further to 15.52 psi, while shear bond strength was 293.90 psi.

Overall, the addition of the powder caused a continuous decline in compressive strength values and had a fluctuating effect on shear bond strength values. The reduction in strength at certain concentrations is due to the role of tea powder as a retarder, which delays the cement hardening time and alters structural density. Excessive addition can lead to strength loss caused by the formation of less homogeneous bonds and increased porosity.

Based on these research results, it can be concluded that the optimum concentration for adding Tea Powder lies in the 0–1% range, as this yields the best combination of compressive strength and shear bond strength compared to the other variations. The phenomenon in which Compressive Strength (CS) values steadily decline while Shear Bond Strength (SBS) values peak at a 1% concentration indicates that these two physical cementing parameters are not directly proportional. This divergence in trends is governed by two opposing physical and chemical mechanisms within the cement slurry.

CONCLUSION

Based on the analysis, data processing, and laboratory discussion regarding the effect of adding tea powder as an additive on the mechanical characteristics of Class G oil-well cement, the following conclusions can be drawn: The addition of tea powder as an additive caused a consistent and continuous decrease in the cement's Compressive Strength. The highest Compressive Strength value was observed in the base cement (0% additive) at 372.52 psi; this value subsequently dropped significantly to 310.43 psi at a 1% concentration, 153.40 psi at 2%, and 61.36 psi at 3%, reaching a minimum of 15.52 psi at a 4% concentration. The addition of tea powder had a fluctuating effect on the Shear Bond Strength between the cement and the casing. Shear Bond Strength reached an optimum peak at a 1% concentration (1,102.13 psi), compared to the base cement without additives (734.75 psi).

However, at concentrations exceeding 1% (i.e., 2%, 3%, and 4%), the interfacial bond strength values declined successively to 881.70 psi, 367.37 psi, and 293.90 psi. The reduction in Compressive Strength and Shear Bond Strength at high concentrations (2% to 4%) is attributed to the characteristics of organic polyphenol compounds (tannins and catechins) in the tea powder, which act as retarding agents (Samura, 2017). These compounds slow down the hydration process of the cement's calcium silicates and delay the hardening time, thereby resulting in the formation of a less homogeneous matrix bond and increasing the cement's internal porosity, which weakens the structural density.

The optimum concentration range for adding tea powder as an additive to Class G drilling cement is between 0% and 1%. Within this concentration range, the cement slurry achieves the best overall performance: the reduction in compressive strength remains within mechanical tolerance limits for drilling operations, while a highly significant increase in shear bond strength occurs, effectively preventing gas or formation fluid leakage.

The primary focus of this study is to examine the effects of adding tea powder on the compressive strength and shear bond strength of API Class G drilling cement. 2. In this laboratory-scale study, the concentration of tea powder was varied across five levels: 0%, 1%, 2%, 3%, and 4% by weight of cement (BWOC). To refine and advance future research on the use of tea powder as an alternative additive in drilling cement, the following key recommendations are made:

Further research should be conducted using more granular and specific concentration variations within the 0% to 1% range (e.g., 0.25%, 0.50%, and 0.75%) to pinpoint the absolute optimum

concentration for enhancing Shear Bond Strength without excessively compromising Compressive Strength.

Comprehensive testing of other physical parameters of the drilling cement slurry is required in accordance with API (American Petroleum Institute) Spec 10 standards; this includes testing for thickening time, fluid loss, free water, and rheological properties (viscosity, yield point, and gel strength).

It is recommended to perform microstructural analysis of the cement using advanced instrumentation—such as SEM (Scanning Electron Microscopy) to visually examine pore morphology, or XRD (X-Ray Diffraction) to identify the formation of crystalline hydration phases resulting from the interaction with organic compounds in the tea powder.

Testing should be conducted under High Temperature High Pressure (HTHP) conditions to simulate actual deep-well environments, given that the thermal stability of the organic compounds in tea powder is significantly influenced by subsurface temperatures.

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