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# Splitting Tensile and Flexural Strengths of Agbabu Bituminous Sand Concrete

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***Abstract:*** **The findings of an experimental investigation into the splitting tensile and flexural strengths of plain concrete produced with Agbabu bituminous sand are presented in this work. Open excavation was used to obtain bituminous sand, which was then crushed with a scoop to sand sizes. A total of eighty-four specimens were cast and tested. The slump test and the compacting factor test were used to assess the concrete's fresh properties. The samples were cured for 7, 14, 21, 28, 56, 90, and 150 days, respectively, before the splitting tensile and flexural strength tests were conducted. According to the findings, bituminous sand concrete is placeable compared to the control. Additionally, the tests demonstrate that the samples' splitting tensile and flexural strengths rose as the curing age increased, albeit at varying rates, with the control concrete achieving the highest strength. The splitting tensile and flexural strength of bituminous sand concrete grew gradually in the early curing ages but dramatically in the later curing ages. Accordingly, bituminous sand concrete may be used for concrete structures that do not need to generate high early splitting tensile and flexural strength, according to the trial results. Additionally, simplified empirical models were put forth to accurately forecast the bituminous sand-containing concrete's splitting tensile and flexural strengths.**

***Keywords:*** **Bituminous sand, Bituminous sand concrete, Flexural strength, Splitting, Regression model, Splitting tensile strength.**

## 1. INTRODUCTION

The construction aggregate industry is an essential part of most developed economies [1]. Concrete, which comprises more than 70% construction aggregate, is the most versatile building material. Author in [2] described concrete as a composite material that resembles stone and is made by combining aggregates (such crushed rock or irregularly shaped stones) with cement (which serves as a binding agent) and water, then letting the mixture dry and solidify. These aggregates are the major components of concrete and have a major role in the development of strength [3]. One of the primary components utilized as a fine aggregate in the manufacturing of concrete is river sand. Authors in [4] reported that the overexploitation of river sand due to an increase in the demand for building materials has had negative effects, including lowering the water table, increasing the depth of the riverbed, and introducing saline into the river. Furthermore, the rising demand has resulted in exorbitant price hikes for obtaining this material, making it extremely challenging to provide the swarming population of a nation like Nigeria with the shelter they need [5]. Authors in [6] observed that urban areas in Africa are experiencing population expansion at a rate that is typically more than twice that of rural areas and [7] conclude that urban construction in Africa is expected to be quintuplicated by 2050, ideally with the use of low-cost beneficial, sustainable, and material-saving technology. One low-cost beneficial material explored in this study is bituminous sand which is made up of sand, heavy oil, and clay that are high in water and minerals [8].

According to [9], world-wide reserves of bituminous sands are estimated at 5.6trillion barrels, occurring in over 70 different countries. On the African continent, some sizable quantities of bituminous sands exist in the Dahomey basin. A large portion of the Gulf of Guinea's continental edge is covered by the Dahomey basin. It stretches from the Okitipupa ridge in Nigeria in the east to the volta delta in Ghana in the west. It is a marginal pull-part basin, also known as a marginal sag basin, that formed during the Mesozoic era when the continental margin foundered, and the African and South American lithospheric plates split apart [9, 10-13].

Nigeria boasts of huge quantities of bituminous sands deposits [14-15]. The bituminous sand deposit in the southwestern Nigeria is one of the notable deposits, estimated to be among the largest in the world [16-17], with a belt of 5-8km wide, spanning about 120km in the South-Easterly direction across four states including Lagos, Ogun, Ondo, and Edo states of Nigeria [18-20]. [21] also noted that the Nigeria bituminous sand reserve is about 42billion barrels and ranked 6th in a list of top ten countries [22].

Despite the abundance of bituminous sand in Nigeria, interest has hardly been directed towards using it to make concrete for the provision of low-cost housing for the teeming population of Nigeria. Thus, this work seeks to investigate the splitting tensile and flexural strengths of concrete made with bituminous sand. This is in line with the findings of the Authors in [23] who concluded that using locally available building materials in construction projects promotes the growth of society.

## 2. EXPERIMENTAL WORKS

### 2.1. Materials

#### 2.1.1 Cement

A 42.5R ordinary Portland cement Dangote brand conforming to [24] and supplied by a retailer in Owerri, Imo state Nigeria was used as the cementitious material in this study.

#### 2.1.2 Fine aggregate

**River sand:** The river sand used as the control for this study was high-quality, surface saturated white, crisp sand from Otamiri river in Owerri, Nigeria. It was free of organic elements and trash.

**Bituminous sand:** Agbabu in Ondo state, which is in the sedimentary landscape of the Dahomey Basin in southwest Nigeria, provided the bituminous sand used in this study. The fine aggregate's mechanical characteristics is found in section 2.2.2.

#### 2.1.3 Coarse aggregate

The coarse aggregate was crushed limestone aggregate (Ajali formation) maximum size 20mm obtained from Jingzang quarry km 40 Enugu – Abakaliki highway Okpoto, Ebonyi State, Nigeria. Before being used, the coarse aggregate was cleaned, rinsed with clean, drinkable water, and dried. The coarse aggregate's mechanical characteristics is found in section 2.2.2.

#### 2.1.4 Water

Fresh, drinkable water was used for concreting; this allowed the cement to hydrate, which caused the concrete to set and solidify.

### 2.2 Procedure and Methodology

The outline of the current research is depicted in Figure 1.

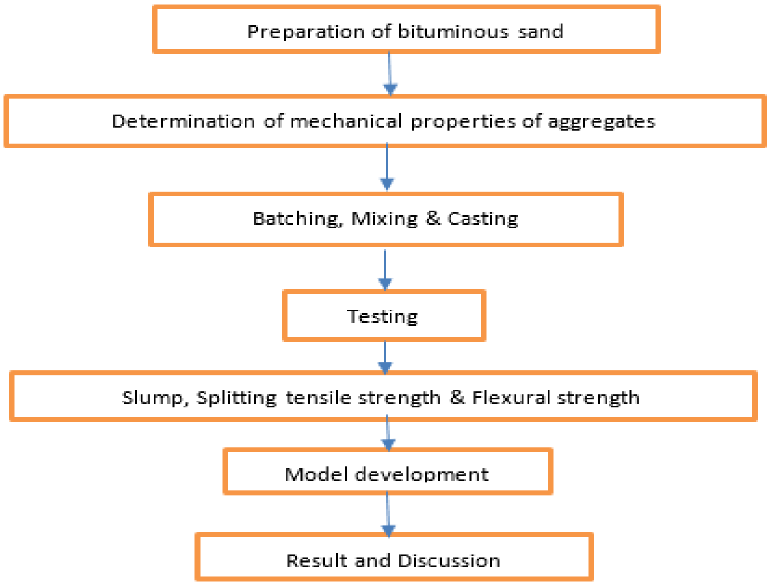


**Fig 1. Schematic of present research**

### 2.2.1 Preparation of bituminous sand

The bituminous sand which was obtained by open excavation from outcrops with the use of pick and or shovel, was in compact and solid form. With the help of a scoop, the sample was crushed into sand-like pieces because it was challenging to work with in this condition. The bitumen present is what gives the bituminous sand its dark to black hue, as may be seen by simple visual inspection.

### 2.2.2 Determination of mechanical properties of aggregates

The mechanical properties of the aggregates used for the current study were determined in accordance with relevant ASTM standards. Sieving was performed according to the ASTM standard [25], The surface moisture content following the ASTM [26] procedure were 0.60%, 0.72% and 0.08%, while the bulk density following the ASTM [27] procedure were 1717kg/m$^3$, 1780kg/m$^3$ and 1677kg/m$^3$, for the specific gravity and water absorption of coarse and fine aggregate following the ASTM [28, 29] procedure were (2.60,0.70%), (2.64,0.91%) and (2.70,0.74%) for the bituminous sand, river sand and granite respectively.

### 2.2.3 Batching and Mixing of concrete

In compliance with the concrete mix ratio of 1:2.2:3.3, the batching was done by weight. The cement was then evenly distributed over the mixture of crushed stone and sand after the coarse and fine aggregates had been combined and spread out on the laboratory's firm, clean floor. The materials were shoveled repeatedly from one end to another and cut with shovel until the mix appeared uniform. After that, water was injected gradually to prevent cement and water from escaping on their own. After that, the mixing process was repeated as for the dry stage until the mixture's color and consistency seemed consistent.

### 2.3 Slump test

Utilizing Abram's slump cone apparatus, the slump test was conducted. The purpose of this experiment was to gauge how well concrete filled. The control concrete and bituminous sand concrete (BSC) were both used in the test. Fresh concrete was poured into the machine in three layers, each containing 25 blows. To allow for concrete distortion on a flat metal plate, the cone was vertically removed. It was measured to determine the new height. The height difference between the cone and the concrete cone upon removal was calculated. Look at table 2.

### 2.4 Preparation of specimens for strengths test

The specimens were prepared firstly by using a brush to grease the inside of the 150-mm x 300-mm cylinder for the splitting tensile strength test and 150-mm x 150-mm x 500-mm beam for the flexural strength test molds to facilitate simple demolding. Secondly, using a mason's trowel, the properly mixed concrete was poured into the cubical molds in three layers. The first, second, and third layers were evenly distributed across the mold's cross section and giving a compaction of 25 blows with a rammer at its own weight in accordance with [30]. The top of each mold was smoothened and leveled, and the outside surfaces cleaned. A total of 42 cubes (21 control and 21 bituminous sand samples) were made for this study. A day later, the firm concrete was removed from the mold and moved to the water-filled curing tank until tested. The laboratory process also considered the precautions noted in [31-32].

### 2.5 Splitting Tensile and Flexural Strength tests

Both the hardened control and bituminous sand concrete cylinders' splitting tensile strength was assessed using a 2000kN SANS hydraulic compressive strength testing machine, and the hardened control and bituminous sand concrete beams' flexural strength was assessed using a 2000kN SANS hydraulic flexural testing machine utilizing the two-point loading test method at 7, 14, 21, 28, 56, 90, and 150 days of curing (see figure 2). The testing apparatus satisfies [33] criteria. In compliance with [34] and [35], the tests were conducted on duplicate samples of 150 mm x 300 mm concrete cylinders and 150 mm x 150 mm x 500 mm concrete beams at each curing age. In total, eighty-four samples were crushed, as shown in Table 1. These tests were conducted in the Structural materials laboratory in federal university of technology Owerri, Imo state, Nigeria.

**Table 1. Number of samples crushed**

| Sample type | Curing ages | Type of strength test | Replicates | No of samples |
|---|---|---|---|---|
| Control-River sand | 7, 14, 21, 28, 56, 90, 150 | Splitting tensile | 3 | 21 |
| Bituminous sand | 7, 14, 21, 28, 56, 90, 150 | Splitting tensile | 3 | 21 |
| Control-River sand | 7, 14, 21, 28, 56, 90, 150 | Flexural | 3 | 21 |
| Bituminous sand | 7, 14, 21, 28, 56, 90, 150 | Flexural | 3 | 21 |
| **Total** | | | | **84** |

**Figure 2 (a) Splitting tensile strength test** **(b) Flexural strength test**

### 2.6 Model Development

Regression analysis was used statistically to perform the empirical correlation using an MS Excel spreadsheet. The models for estimating splitting tensile and flexural strength were created following the procedure outlined in [36]. The variables' relationships were established. The mathematical model's statistical adequacy was tested at a 95% accuracy level utilizing the statistical student's t-test.

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The following two hypotheses were tested:

i. The null hypothesis states that, at a 95% accuracy level, there is no considerable discrepancy between the laboratory and predicted concrete cylinder and beams splitting tensile and flexural strengths data.

ii. Alternative hypothesis: At a 95% accuracy level, there is a considerable discrepancy between the laboratory and predicted concrete cylinder and beams splitting tensile and flexural strengths data.

## 3. RESULTS AND DISCUSSION

### 3.1 Slump/Workability test

Table 2 displays the results of the slump test. The table shows that, in comparison to the control, the bituminous sand concrete (BSC) had a higher slump value. The presence of bitumen in the bituminous sand concrete (BSC) improved the rheological behavior of the concrete thus making the concrete more workable. Additionally, it is reasonable to believe that bitumen disrupted the cement-water binding interactions, preventing or postponing the cement particles' full hydration [37].

**Table 2. Slump values of samples**

| Sample | Slump (mm) | Degree of workability |
|---|---|---|
| control | 30 | Low |
| BSC | 55 | Medium |

### 3.2 Splitting Tensile Strength

The result of the average Splitting Tensile strength of concrete (Control and Bituminous sand samples) is shown in figure 3. All the samples' splitting tensile strengths rose over time, but at varying rates. The bituminous sand concrete (BSC) sample's values rose with curing age but did not surpass the control at the various testing ages, whereas the control concrete sample consistently maintained the greatest splitting tensile strength values with time. The control concrete had splitting tensile strengths of 2.42N/mm$^2$, 2.62N/mm$^2$, 2.74N/mm$^2$, 3.38N/mm$^2$, 3.57N/mm$^2$, 3.66N/mm$^2$, 3.83N/mm$^2$ at 7, 14, 21, 28, 56, 90 and 150days of curing respectively. The bituminous sand concrete (BSC) had splitting tensile strengths of 0.63N/mm$^2$, 1.12N/mm$^2$, 1.20N/mm$^2$, 1.48N/mm$^2$, 1.53N/mm$^2$, 1.61N/mm$^2$, 1.68N/mm$^2$ at 7, 14, 21, 28, 56, 90 and 150days of curing respectively, bringing about 74% and 56% increase in splitting tensile strength of the control concrete compared to the Bituminous sand concrete at 7 and 150days of curing. The BSC sample had 63% increase in splitting tensile strength development from the 7day curing age to 150day curing age respectively. The fact that bituminous sand concrete (BSC) gets stronger over time suggests that more calcium silicate hydrate is created as the hydration process goes on, which raises the concrete's splitting tensile strength.

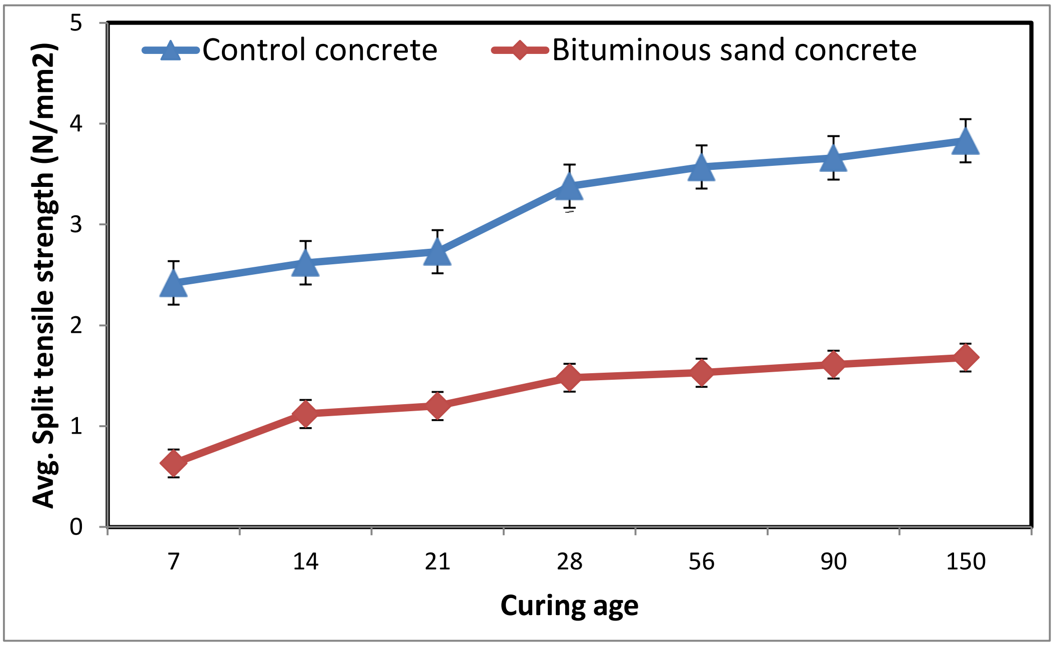


**Figure 3: Average splitting tensile strength of concrete (control and bituminous sand sample)**

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### 3.3 Flexural Strength

The result of the average Flexural strength of concrete (Control and Bituminous sand samples) is shown in figure 4. The flexural strength for all the samples increased with time just like the splitting tensile strength but at different rates. The control concrete had flexural strengths of 5.71N/mm$^2$, 5.88N/mm$^2$, 6.73N/mm$^2$, 7.54N/mm$^2$, 7.83N/mm$^2$, 8.46N/mm$^2$, 8.66N/mm$^2$ at 7, 14, 21, 28, 56, 90 and 150days of curing respectively. The bituminous sand concrete (BSC) had flexural strengths of 1.78N/mm$^2$, 1.86N/mm$^2$, 3.37N/mm$^2$, 4.72N/mm$^2$, 4.98N/mm$^2$, 5.12N/mm$^2$, 5.38N/mm$^2$ at 7, 14, 21, 28, 56, 90 and 150days of curing respectively, bringing about 68.8% and 38% increase in flexural strength of the control concrete compared to the Bituminous sand concrete at 7 and 150days of curing. The BSC sample had 66.9% increase in flexural strength development from the 7day curing age to 150day curing age.

Comparing the splitting tensile and flexural strengths, it is very clear that bituminous sand concrete has better flexural strength development capacity than splitting tensile strength.

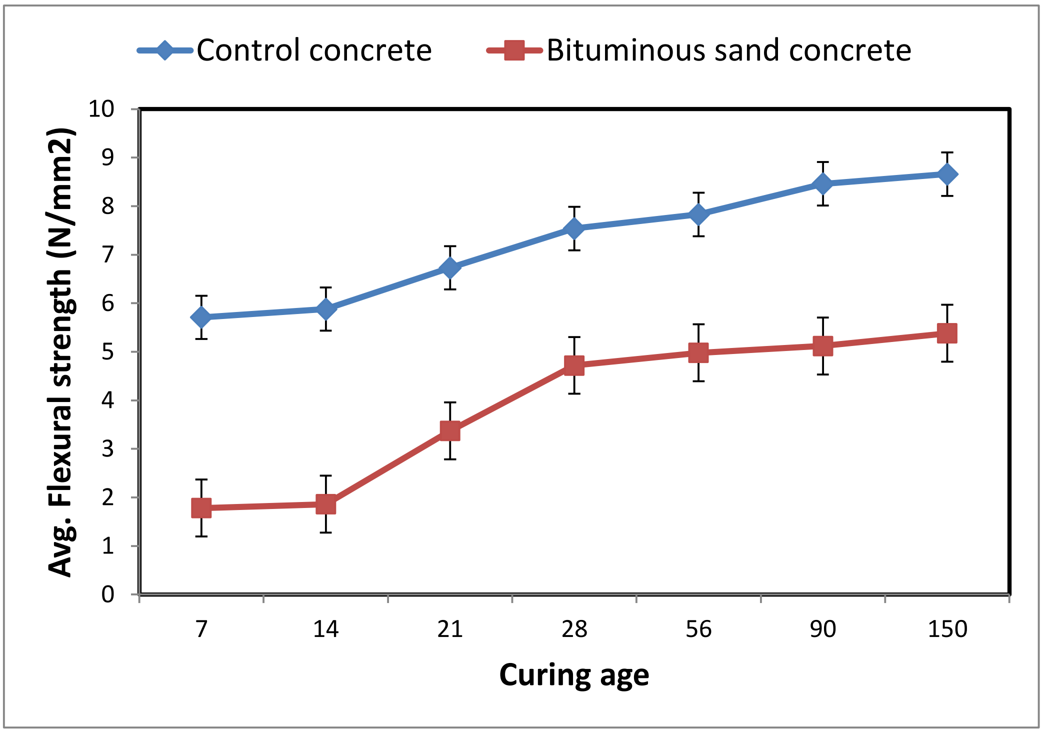


**Figure 4: Average flexural strength of concrete (control and bituminous sand sample)**

### 3.4. Effect of Bituminous sand on the Strength of Concrete

Bituminous sand had a somewhat detrimental effect on the split cylinder tensile and beam flexural strengths of concrete. As the curing age increased, the control values consistently increased in all strengths. The strength of cement-based products cured in uncontaminated water rises with age, thus this is not surprising. Despite a slower rate of strength development, the bituminous sand concrete beams and cylinders' strengths similarly increased with curing age.

This reduction in strength could be attributed to bitumen found in the bituminous sand, which is a component of the microstructure of the concrete matrix. It is safe to say that there may have been dilation of the gel, weakening of the cohesive forces in the paste, and the subsequent rise in the internal hydraulic pressure as a result of the bitumen's absorption. These factors could have contributed to the low strength development of the concrete cylinders and beams. The outcome of this research as per splitting tensile strength and flexural strength reduction is in agreement with the findings of past researchers [38,39], on the adverse effect of hydrocarbons on concrete.

Since the splitting tensile and flexural strength development of bituminous sand concrete increases with increase in curing ages, it is acceptable for concrete structures that do not require high early strength development.

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### 3.5. Model

The models developed for the BSC is shown in 1 and 2. $Y_{st}$ represents splitting tensile strength, $X_1$ represents curing age in days and $X_2$ represents dry density in $Kg/m^3$ while $Y_f$ represents flexural strength, $Q_1$ represents curing age in days and $Q_2$ represents dry density in $Kg/m^3$.

$$Y_{st} = -34.10 - 0.0037X_1 + 0.017X_2 \quad (1)$$

$$Y_f = -17.47 - 0.0045Q_1 + 0.0093Q_2 \quad (2)$$

According to the results of the t-test, the alternative hypothesis is rejected, and the null hypothesis is accepted. In other words, at a 95% accuracy level, there is no discernible difference between the model-predicted concrete cylinder and beam splitting tensile and flexural strength results and the laboratory data. As a result, the developed models are sufficient. Tables 3 and 54 show the models predicted values of splitting tensile strength and flexural strength for the seven observations for control and bituminous sand concrete samples respectively.

**Table 3. Model Predicted splitting tensile strength of control and bituminous sand concrete**

| Observation | **Splitting tensile strength** | | | |
|---|---|---|---|---|
| | Control concrete | | Bituminous sand concrete | |
| | Predicted | Residual | Predicted | Residual |
| 1 | 2.343893703 | 0.076106 | 0.690933879 | -0.06093 |
| 2 | 2.844279031 | -0.22428 | 1.015853347 | 0.104147 |
| 3 | 3.024802253 | -0.2948 | 1.245287329 | -0.04529 |
| 4 | 3.187529203 | 0.192471 | 1.538265634 | -0.05827 |
| 5 | 3.32338086 | 0.246619 | 1.499118684 | 0.030881 |
| 6 | 3.47923302 | 0.183077 | 1.533379517 | 0.07662 |
| 7 | 4.009191649 | -0.17919 | 1.72716161 | -0.04716 |

**Table 4. Model Predicted Flexural strength of control and bituminous sand concrete**

| Observation | **Flexural strength** | | | |
|---|---|---|---|---|
| | Control concrete | | Bituminous sand concrete | |
| | Predicted | Residual | Predicted | Residual |
| 1 | 5.484766103 | 0.225234 | 1.526493673 | 0.253506 |
| 2 | 6.399264489 | -0.51926 | 2.221880856 | -0.36188 |
| 3 | 7.099676206 | -0.36968 | 3.978389761 | -0.60839 |
| 4 | 7.202598413 | 0.337402 | 4.013245694 | 0.706754 |
| 5 | 7.568882601 | 0.261117 | 4.849109251 | 0.130891 |
| 6 | 8.120137922 | 0.339862 | 5.238018084 | -0.11802 |
| 7 | 8.934674266 | -0.27467 | 5.382862682 | -0.00286 |

## 4. CONCLUSIONS

This research investigated the splitting tensile strength and flexural strength properties of agbabu bituminous sand concrete. The Bituminous sand that was used as an alternative to river sand as a fine aggregate material was gotten from agbabu. Thus, based on the experimental and statistical results, the following conclusions are arrived at:

- There was an increase in slump of the bituminous sand concrete (BSC) compared to the control.
- The bituminous sand concrete splitting tensile strength and flexural strength increased with increase in curing age.
- The bituminous sand concrete has a better flexural strength development capacity than splitting tensile strength.
- The models developed with good coefficients of determination were tested and found to be adequate.

**Declaration of competing interest**

The authors state that there are no conflicts of any commercial or associative interest in connection with the study submitted.

**Data availability**

The article contains the original contributions made during the study; additional questions can be forwarded to the corresponding author.

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