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RSM-Based Optimized Compressive Strength of Mix Design Concrete Aggregates of Clamshell, Iron Sand, and Epoxy Resin

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Abstract The need for environmentally friendly concrete that has above average compressive strength continues to be pursued to meet the infrastructure needs of humans. The availability of materials derived from organic waste such as clamshells is thought to be used as an aggregate from concrete which is more environmentally friendly when combined with previously known inorganic materials. The purpose of this study was to optimize the compressive strength of concrete-filled with clamshell powder (CSP), iron sand, and epoxy resin. An optimization approach based on response surface methodology (RSM) was used in this study. Iron sand used is 10% (w/w). The CSP used is in the range of 1 to 4% (w/w). The epoxy resin used is in the range of 10.5 to 14.40% (w/w). The temperature and time of curing were carried out in 301 to 333 K and 4 hours, respectively. The age of concrete is measured in the range of 1 to 28 days. The cylindrical molded concrete has a diameter and height of 100 mm and 200 mm, respectively. All samples were measured for compressive strength using the UTM RTF-1350 (capacity of 250 kN). The concrete composition with epoxy resin (11.93%, w/w) to the standard concrete aggregate mixture produced the highest compressive strength (71.49 MPa). However, the addition of CSP as a filler in concrete has provided a compressive strength (31.18 MPa) above concrete by the Indonesian National Standard (SNI). The combination of CSP and epoxy resin under high-temperature curing conditions is possible to increase the compressive strength of concrete to 45.65 MPa.

Keywords Clamshell Powder, Concrete, Eco-friendly Concrete, Epoxy Resin, RSM

1. Introduction

Concrete is the most frequently utilized building material. Since concrete has a greater variety of applications in a building than other materials and its availability and worldwide influence, concrete is chosen internationally in the long term. Concrete combines water, cement, aggregates, and occasionally an additive. Cement is the primary binding force in concrete, but it's also the most expensive and is used more than water worldwide. For example, since 2017, studies have shown that more than 4 billion metric tons of cement are made each year, which works out to 0.56 tons for each person on Earth, and this is expected to keep going up [1-3].

Waste materials used instead of cement in the research world are being looked for until now. Every year, more and more waste materials are produced, and they can't be thrown away traditionally. Therefore, one solution to the problem of handling waste is to use it as an alternative material in construction as a filler in concrete or so-called sustainable concrete. Seashells from different mollusks are a significant source of waste, especially clamshells from *Anadara Granosa*. There aren't enough ways to get rid of clamshells. Another research estimated that between 10 and 20 million tons of shell trash are discarded yearly due to seashell processing [4]. Seashell disposal harms the environment and contributes to pollution through both water leakage and landfill management challenges.

Clamshell as a powder (CSP) is reported to have a similar chemical composition as limestone used in concrete production. In addition to its abundant potential in nature due to the rapid proliferation of shellfish, CSP sources are more environmentally friendly to be used as fillers for concrete. This is especially true for concretes that settle around the coast where this shell material is straightforward to find. However, an appropriate composition needs to be reviewed to standard the quality of CSP concrete.

Building parameters such as fresh and hardened concrete should be considered to determine the efficacy of shell integration in concrete. Appropriate planning techniques will avoid over or under-design [5]. Concrete with the main ingredient clamshell from *Anadara Granosa* mixed with iron sand and epoxy resin under curing conditions was investigated to determine its compressive strength. Therefore, this study aims to optimize the compressive strength of concrete filled with clamshell powder (CSP), iron sand, and epoxy resin under curing conditions using response surface methodology (RSM).

2. Materials and Methods

2.1. Mechanical Properties of Concrete Composing Materials

The primary materials used in this research are cement, sand, gravel, and iron sand. Each concrete sample uses the initial standard of a concrete composition according to SNI in the form of a water-cement ratio of 0.51. Furthermore, the amount of cement used was 373 g. The amount of water used is 190 l. The coarse aggregate and sand aggregates are 1839 g and 1080 g, respectively. These materials were obtained from material market around the research site (Lampung, Indonesia). The physical properties of the materials used are presented in Table 1.

2.2. Material Composition of Concrete with CSP

Clamshells (*Anadara granosa*) are an abundant organic waste and are now popularly used as a substitute for concrete aggregates. The clamshell used in this study was powder form with properties presented in Table 2. The amount of clamshell powder (CSP) used in concrete aggregates was 0, 1, 2, 3, 4, 6, 8, and 10% (w/w).

Table 1. Material properties of concrete composition

Physical properties	Material type			Unit
	Sand	Gravel	Iron sand	
Bulk specific gravity	2.61 ± 0.0057	2.52 ± 0.0035	4.35 ± 0.0071	-
Bulk SSD specific gravity	2.64 ± 0.0049	2.57 ± 0.0014	4.37 ± 0.0021	-
Apparent specific gravity	2.68 ± 0.0042	2.65 ± 0.0007	4.47 ± 0.0127	-
Absorption	0.92 ± 0.0148	1.95 ± 0.0608	0.61 ± 0.1004	%
Weight per volume	1.47 ± 0.0396	1.31 ± 0.1053	2.41 ± 0.0601	g/cm³
Sludge content	0.44 ± 0.1273	0.58 ± 0.0354	n/a	%

Table 2. Physical properties of CSP

Physical properties	Value	Unit
Bulk specific gravity	2.83 ± 0.0375	-
Bulk SSD specific gravity	2.84 ± 0.0255	-
Apparent specific gravity	2.86 ± 0.0028	-
Absorption	0.30 ± 0.4271	%

2.3. Material Composition of Concrete with Epoxy Resin

Epoxy resin is a polymer of epoxide groups that can strengthen the compressive strength of concrete. Several studies have stated that concrete with epoxy resin is called polymer concrete [6-9]. In this study, the amount of epoxy resin used as a concrete admixture was 10.5, 11.8, 12.5, 13.0, 13.8, and 14.4% (w/w).

2.4. Curing Condition Treatment on Concrete

The curing condition in this research aims to keep the concrete from losing water quickly and as an action to maintain the moisture so that the concrete can achieve the desired concrete quality. The curing temperature used in this study was 301, 313, 323, 333, and 343 K. The curing time used in this study was 0, 2, 3, and 4 hours. Curing is carried out in a water bath whose water temperature can be controlled with the specified time.

2.5. Instrumentation and Procedure Testing Compressive Strength of Concrete

The procedure for making a standard concrete in this study follows the Indonesian National Standard (SNI) 03-2834-2000. Additionally, the composition of this SNI concrete mixture is utilized as a baseline against which the compositions of the other types of concrete employed in this study may be compared. Compressive strength was measured using the Universal Testing Machine RTF-1350 with a capacity of 250 kN. The cylindrical molded concrete has a diameter of 100 mm and a height of 200 mm [10-12]. The ASTM C39 standard is used to determine concrete age [13-15].

2.6. Response Surface Methodology

Response surface methodology (RSM) is an approach for optimizing responses in the combination of different or more quantitative parameters. A goal for each parameter is needed to get an optimal condition from the RSM approach. The plan in optimizing the composition of materials and curing treatment used in concrete through the RSM approach is presented in Table 3. Iron sand material was chosen to be in range because this material is abundant, especially in Indonesia, and can increase the compressive strength of concrete [16]. The CSP aggregate material was chosen with the maximum goal so that the waste from CSP can be utilized optimally in concrete [17]. Epoxy resin was selected with a minimum purpose to strengthen the compressive strength of concrete to make it more environmentally friendly [6]. The temperature and curing time are chosen with a minimum goal to optimize the compressive strength of the concrete but still with minimal energy [18]. Age of concrete is selected with a goal in range to maximize the time for the concrete to reach its maximum compressive strength.

Table 3. The goal of material composition parameters and curing treatment

Parameter	Goal	Low	High	Unit
Iron sand agregat	In range	0	10	%
CSP agregat	Maximize	0	4	%
Epoxy resin	Minimize	10.50	14.40	%
Time of curing	Minimize	0	4	hr
Temperature of curing	Minimize	301	333	K
Age of concrete	In range	1	28	day

3. Result and Discussion

3.1. Influence of CSP on Compressive Strength of Concrete

Figure 1 depicts the compressive strength response surface plots as a function of CSP parameters. The optimal composition of CSP aggregate is 4% at 28 days of concrete age. The compressive strength of concrete with the addition of CSP is 31.18 MPa. The compressive strength of this study is in line with that found by Olivia, et al. [19], who reported that a mixture of 4% CSP in concrete would yield a compressive strength of about 32.24%.

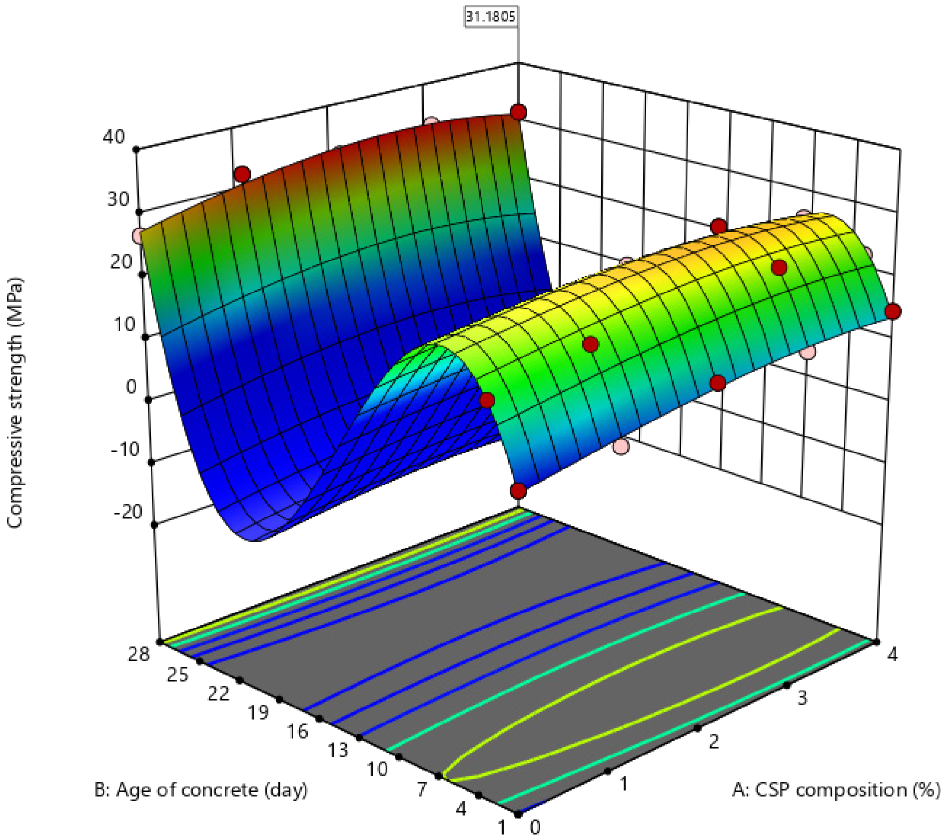

Figure 1. Response surface plot for CSP aggregate on concrete

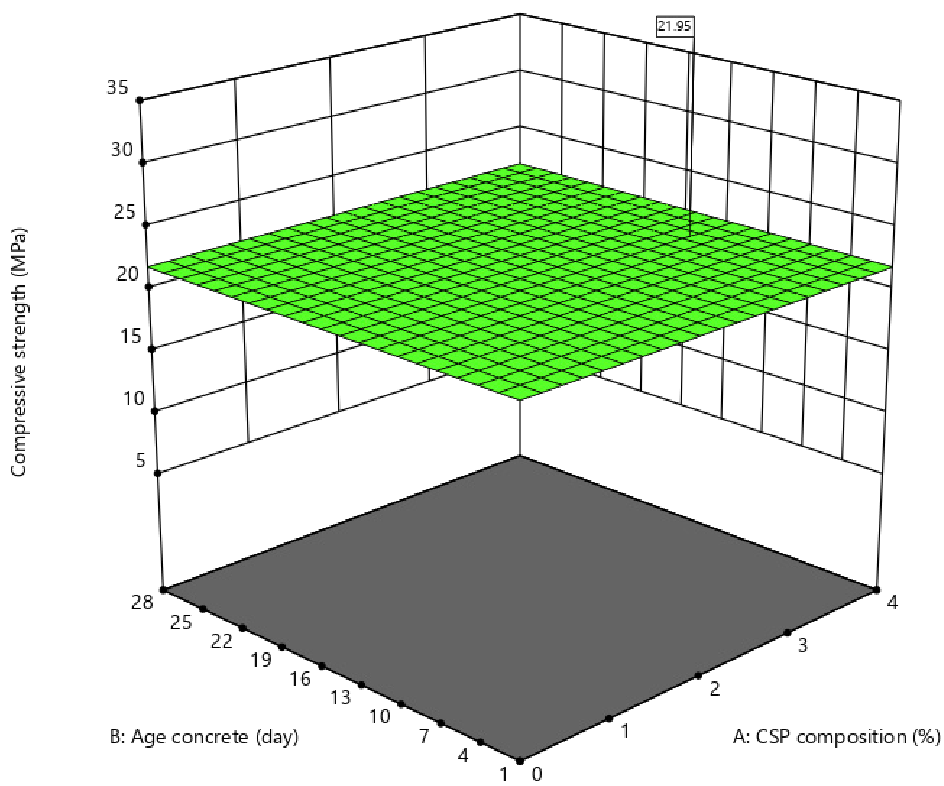

Figure 2. Response surface plot for CSP under curing condition

3.2. Influence of CSP under Curing Condition on Compressive Strength of concrete

Figure 2 shows the compressive strength response surface plots as a function of the CSP parameters under hot water curing conditions. The optimal composition of CSP aggregate is 3.47% at 11.70 days of concrete age. The optimal curing temperature and curing time are 312.75 K and 1.26 hr, respectively. The compressive strength of concrete with a filler of CSP under hot water curing conditions is 21.95 MPa. Compressive strength is flat with increased CSP composition on the concrete age up to maximum value. This also shows that mixing CSP in concrete on the age of concrete from one day to 28 days does not significantly differ. Concrete with this mixture can be tested for compressive strength the next day after molding. Concrete under hot water curing conditions filled with CSP has characteristics that are not in line with the results of Mohamed [20]. They found that water curing treatment of concrete can increase the compressive strength of concrete up to about 35 MPa. It is assumed that the aggregates of CSP have characteristics that cannot blend with cement if treated with hot water curing conditions.

3.3. Influence of Epoxy Resin on Compressive Strength of concrete

Figure 3 shows the response surface plots of compressive strength as a function of the epoxy resin parameters. The optimal composition of the epoxy resin aggregate is 11.93% (w/w) at two days of concrete age. The compressive strength of concrete with epoxy resin is 71.49 MPa. The increase in compressive strength of concrete due to the addition of epoxy resin was also found in Paper [7-9]. The epoxy resin was discovered to have no disadvantages in compressive strength development.

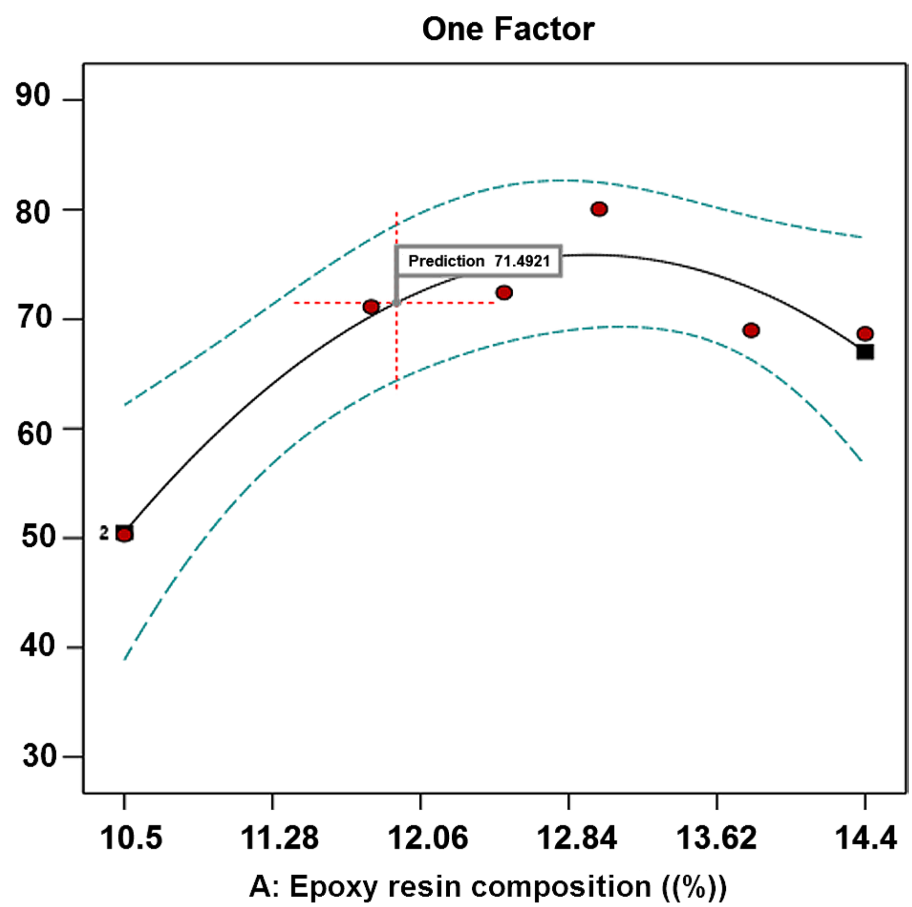

Figure 3. Response surface plot for epoxy resin on concrete

Figure 4 shows the response surface plots of compressive strength as a function of the combined epoxy resin and iron sand parameters. It can be seen that with the increase in epoxy resin, the compressive strength increases, whereas, with the increase in iron sand, the compressive strength increases up to maximum value. This shows that epoxy resin and iron sand parameters significantly affect the compressive strength of the concrete. The optimal composition of epoxy resin aggregate is 10.5% (w/w), with iron sand of 10% (w/w). The compressive strength of concrete with combined epoxy resin and iron sand is 70.80 MPa.

3.4. Influence of Epoxy Resin under Curing Condition on Compressive Strength of Concrete

Figure 5 shows the response surface plots of compressive strength as a function of the combined epoxy resin and iron sand parameters under hot water curing conditions. It is explicit that compressive strength is flat with increased epoxy resin and iron sand. This shows no significant increase in the compressive strength of concrete when mixing epoxy resin and iron sand simultaneously. The use of minimum epoxy resin with more iron sand is the best choice in terms of the compressive strength of the resulting concrete. The optimal composition of the epoxy resin aggregate is 11.60% (w/w), with iron sand of 5.68% (w/w). The optimal curing temperature and curing time were 337.74 K and 1.12 hr, respectively. The compressive strength of concrete with combined epoxy resin and iron sand is 70.64 MPa. Hot water curing conditions on concrete with epoxy resin will also increase the compressive strength to about 80 MPa [9].

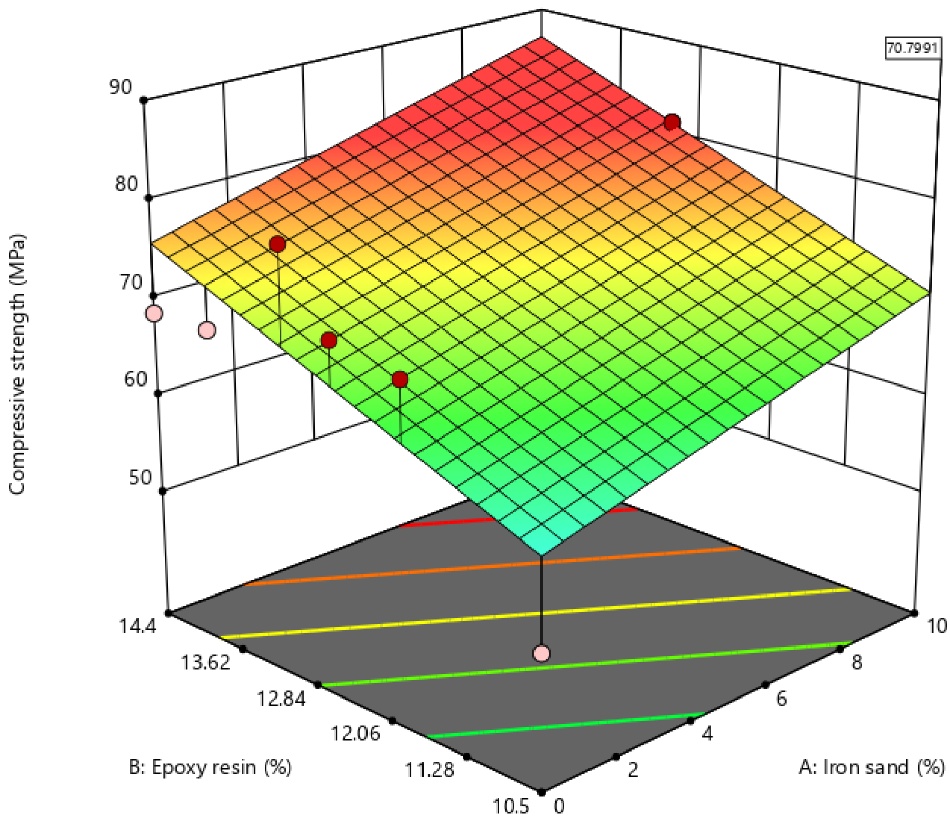

Figure 4. Response surface plot for combined epoxy resin and iron sand on concrete

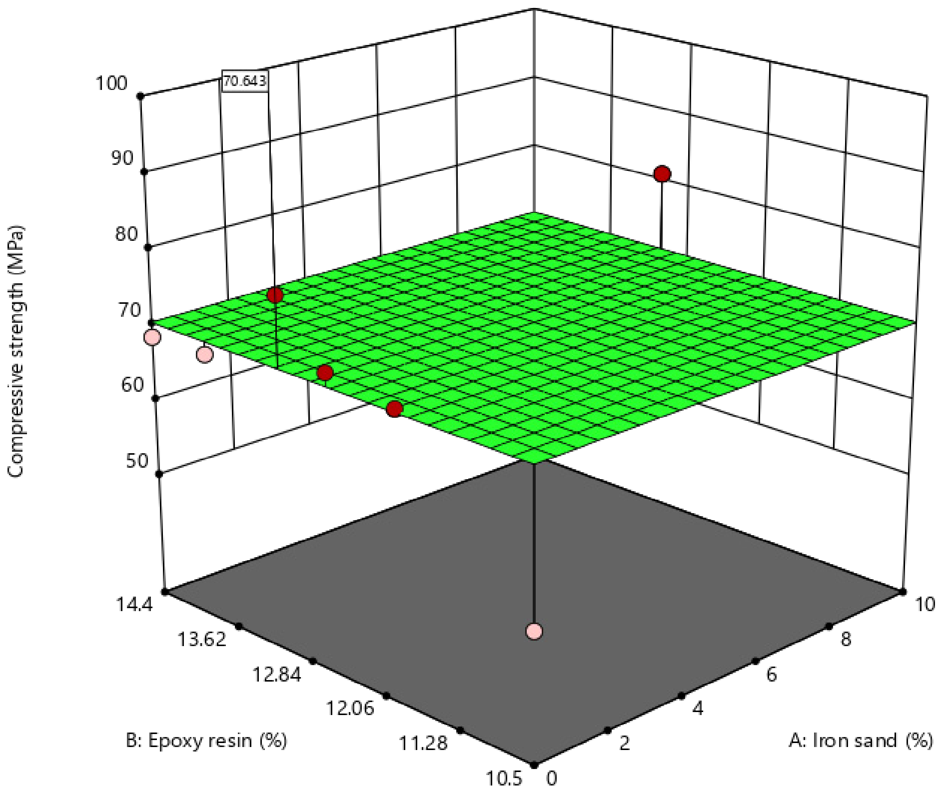

Figure 5. Response surface plot for combined epoxy resin and iron sand on concrete under curing condition

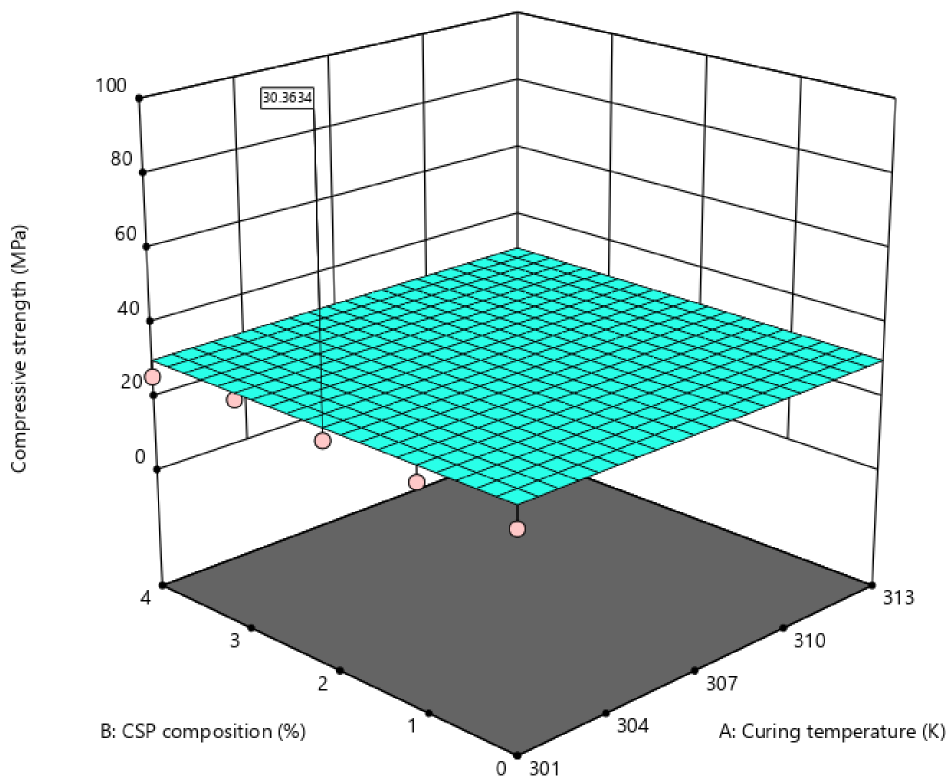

Figure 6. Response surface plot for combine CSP and epoxy resin under middle temperature curing condition

3.5. Influence of Combined CSP and Epoxy Resin under Curing Condition on Compressive Strength of Concrete

Figure 6 shows the compressive strength response surface plots as a function of the combined CSP and epoxy resin parameters under middle-temperature curing conditions. It is precise that compressive strength is flat with increased CSP composition and curing temperature. This shows no significant increase in the compressive strength of concrete when mixing CSP under hot water curing conditions at the same time. The use of larger CSP with lower curing temperature is the best choice in terms of the compressive strength of the resulting concrete. The optimal composition of the epoxy resin aggregate is 3.99% (w/w), with a CSP composition of 3.90% (w/w) at 3.73 days of the age of concrete. The optimal curing temperature and curing time are 311.63 K and 0.32 hr, respectively. The compressive strength of concrete with the addition of combined epoxy resin and iron sand is 30.36 MPa. The combination of CSP treatment and epoxy resin under curing conditions has not increased the compressive strength significantly. However, the obtained compressive strength has exceeded the SNI of concrete quality.

Figure 7 shows the compressive strength response surface plots as a function of the combined CSP and epoxy resin parameters under high temperature curing conditions. The optimal composition of the epoxy resin aggregate is 2.94% (w/w), with a CSP composition of 4.0% (w/w) at 27.97 days of concrete age. The optimal curing temperature is 301.0 K. The compressive strength of concrete with combined epoxy resin, and iron sand is 45.65 MPa. The quality of the compressive strength obtained from this treatment has exceeded the SNI for testing concrete [21].

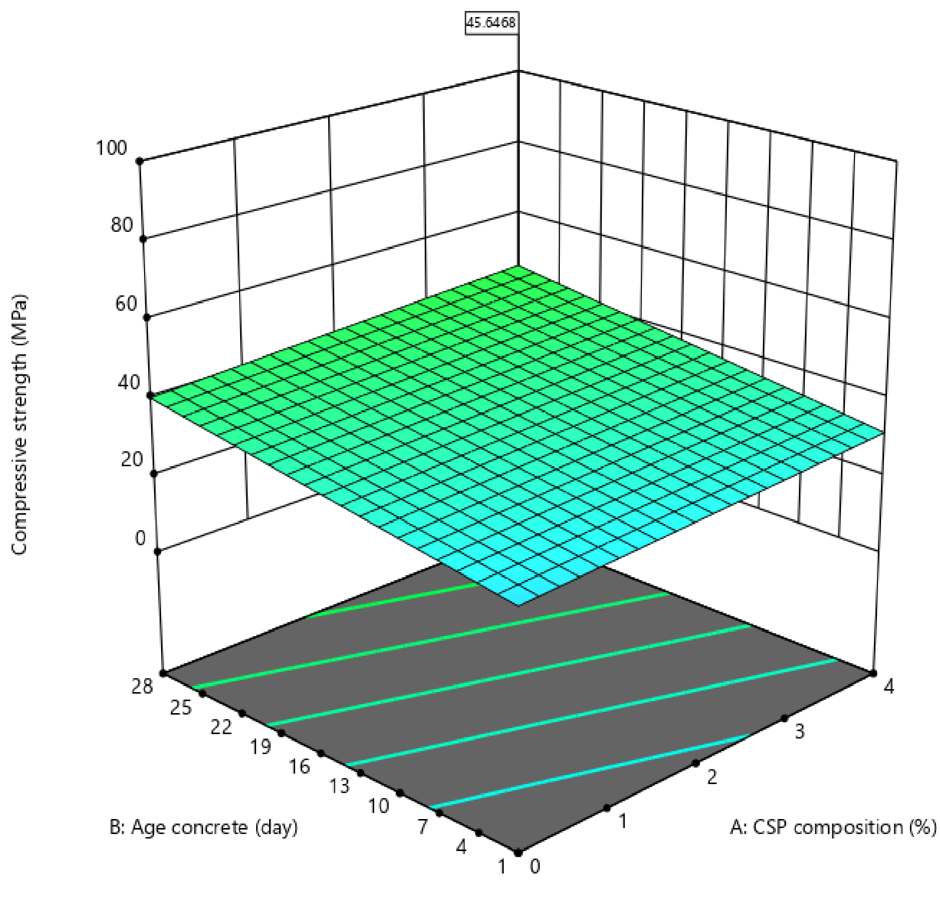

Figure 7. Response surface plot for CSP and epoxy resin under high temperature curing condition

4. Conclusions

Optimized mix design concrete using CSP, iron sand, and epoxy resin under curing conditions based on response surface methodology (RSM) has been investigated. CSP as a filler in concrete can provide a compressive strength of 31.18 MPa. However, CSP as a filler in concrete under hot water curing conditions (312.75 K, 1.26 hr) could not increase the compressive strength (21.95 MPa). The addition of epoxy resin (11.93%, w/w) to the standard concrete aggregate mixture can increase the compressive strength of concrete to 71.49 MPa. Unfortunately, the combination of epoxy resin (10.5%, w/w) and iron sand (10%, w/w) in a standard concrete aggregate mixture cannot increase the compressive strength of concrete (70.80 MPa).

On the other hand, the addition of epoxy resin (11.93%, w/w) to the standard concrete aggregate mixture under hot water curing conditions (337.74 K, 1.12 hr) also did not increase the compressive strength of concrete compared to without curing condition (70.64 MPa). The combination of CSP and epoxy resin under high-temperature curing conditions (45.65 MPa) gave the concrete compressive strength more remarkable than the moderate temperature curing conditions (30.36 MPa). This research suggests that structural engineers should consider using waste such as CSP in concrete without reducing the standard of the required compressive strength. This CSP application will indirectly reduce the existing waste, especially for buildings on the coast where this CSP can easily be found. The future work of this study is to evaluate the concrete with the selected components to be tested on the condition of the existing building on the coast.

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