
RESEARCH ARTICLE

Analysis of Compressive Strength of Sulfur Concrete

Eri S. Romadhon¹ ✉ and Achmad Hanif²

^{1,2}Civil Engineering Study Program Jayabaya University

Corresponding Author: Eri S. Romadhon, **E-mail:** erromadhon63@gmail.com

ABSTRACT

One of the best concrete mixes to reduce environmental impact is using sulfur concrete. The use of sulfur, as a waste material for enterprises, for the production of building materials is efficient due to the disposal of waste and its contribution to environmental protection. Sulfur concrete material has high compressive strength, low hydraulic conductivity, and high resistance to water permeation and is particularly resistant to corrosion in acid and salt environments. Sulfur concrete is more resistant to corrosion. Waterproofing reduces fatigue under repetitive load, develops strength very high start, fast hardens, saves time to manufacture, and holds to an aggressive environment. The aims of this study were 1) To determine the compressive strength of sulfur-bonded concrete with an aggregate ratio, 2) To determine the compressive strength of concrete based on the percentage of sulfur binding material from the combined aggregate weight and specific gravity of the concrete 3) To determine the strength of the sulfur-bonded concrete with a maximum age of 28 days. The research method used is an experimental method based on calculating the density of concrete specimens and the volume of the mould for sulfur concrete specimens. The results showed that 1) the best percentage of mixed material was aggregate fine and coarse 40%: 60%. 2) With use pro percentage sulfur 25%, 27.5%, 30%, 32.5%, 35%, 37.5% and 40% of heavy aggregate combined and weight type concrete 2400 kg/m³. 3) Research results obtained maximum strength sulfur concrete 28 days old of 429.5 kg/cm² at 32.5% sulfur percentage and the lowest 250.5 kg/cm² at the percentage of sulfur 25%.

KEYWORDS

Strong press concrete, sulfur concrete, sulfur polymer concrete

ARTICLE DOI: [10.32996/jmcie.2022.3.2.2](https://doi.org/10.32996/jmcie.2022.3.2.2)

1. Introduction

In the construction business, Portland cement concrete (PCC) has become the most extensively utilized concrete (Dugarte, Arguelles, & Torres, 2019). Concrete's performance is influenced by the ingredients that make it up: water, cement, and aggregates. Portland cement, along with water, is the critical component in concrete technology that binds and prevents aggregates from becoming a solid mass [Yanita, 2020]. Concrete is used in practically every structure, including sidewalks, bridges, buildings, tunnels, and dams. Scientists are actively investigating the most environmentally friendly concrete mix, particularly the cement component, notorious for its significant carbon emissions [Djamil, 2017].

Concrete is a common building material that produces many pollutants with negative environmental consequences throughout its life cycle. As a result, solutions for reducing concrete's environmental impact and assessing its environmental impact from the standpoint of a life cycle assessment (LCA) must be developed. Globally, investigations on LCA concerning greenhouse gas emissions from concrete are currently being conducted as a countermeasure to climate change [Kim, 2016]. The enormous need for cement-based materials for sustainable building and infrastructure systems is causing increasing concern, as cement production produces large greenhouse gas (GHG) emissions and places significant pressure on resources [Miller, 2020]. Recycling building and demolition debris have become increasingly important as the construction industry strives for sustainability. New construction materials made from recycled construction and demolition waste have also contributed to these environmentally friendly activities. The use of recycled aggregate as an alternative to traditional natural concrete has been investigated to achieve a more sustainable future [Senaratne, 2017].

Copyright: © 2022 the Author(s). This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC-BY) 4.0 license (<https://creativecommons.org/licenses/by/4.0/>). Published by Al-Kindi Centre for Research and Development, London, United Kingdom.

Cement is still used as an adhesive in Indonesian concrete production. In other nations, such as Canada, sulfur concrete has been created for over 20 years, with sulfur as one of the constituents, and the adhesive has produced satisfactory results. Development strength starts strong with intriguing characteristics like corrosion resistance, waterproofing, and reduced fatigue under load repetition. Concrete can be used for both structural and non-structural purposes. It hardens quickly, making it simple to change the mould, and it finishes quickly, saving time in the manufacturing process and allowing it to withstand a demanding environment [Vroom, 1998]. Sulfur concrete (SC) is a relatively new form of construction material that has been used in construction engineering because of its excellent corrosion resistance and quick setting and hardening. SC is brittle and has a considerable hardening shrinkage, so it must be changed throughout usage [You, 2021]. Sulfur concrete qualities are provided by a sulfur polymer created by combining conventional sulfur with modifiers that prevent sulfur crystallization, resulting in a stable sulfur polymer structure [8]. The workability of sulfur-based concrete substantially impacts the structure, which is strongly reliant on the sulfur concentration, melt viscosity, filler characteristics, aggregate type, and type and concentration of modifying additives. Compressive strength, deformability, bending, and tension characteristics for several sulfur-based concrete compositions were fully discussed. The ability of sulfur-based concrete to survive in various harsh settings has shown that it is more successful than OPC concrete at mitigating the negative impacts of harsh environments. Due to waste disposal and contributions to environmental preservation, the use of sulfur as waste material for businesses to manufacture construction materials is efficient. The melting/freezing points of sulfur vary depending on the solid allotropes being considered (melted), the temperature, and the pressure of the mixture. Sulfur-based concrete can benefit from various additives to improve its engineering and microstructural qualities. Sulfur-based concrete reaches ultimate strength in a few hours (3–6 h) without particular temperature or moisture requirements, especially at room temperature [9]. Sulfur polymer concrete (SPC) has high compressive strength, low hydraulic conductivity, excellent resistance to water permeation, and corrosion resistance in acid and salt conditions [Fediuk, 2020].

A preliminary test by Jawad & Al-Qudah (1994) showed that the compressive strength of sulfuric concrete could reach 66.2 MPa at the age of 28 days, and at the age of 24 hours, it has reached 76% of the strength of 28 days. Young's modulus is almost the same as cement concrete, but sulfur tank concrete is vital at a higher frequency than ordinary concrete. Sulfur concrete has low water permeability and a weight content of 2,421 kg/m³. The shrinkage of the prepared hardened sulfur concrete is about 4%. By replacing portland cement with sulfur, air pollution in portland cement can be avoided so that the air becomes clean, and limestone mining can be avoided to preserve nature for future generations. If not, we as the younger generation are concerned, then who else and there is functioning as a scholar. It only applies to yourself but is valuable for the environment and future generations. Sulfur concrete with optimal sulfur content produces higher compressive, tensile, and flexural strength than cement-based concrete [Mohamed, 2021]. SPC materials can be considered a promising alternative to hydraulic cement-concrete composites, especially in the radiation and nuclear technology sectors [Szajerski K, 2020]. Based on the description above, the objectives of this research are 1) To determine the compressive strength of sulfur-bonded concrete with an aggregate ratio, 2) To determine the compressive strength of concrete based on the percentage of sulfur binding material from the combined aggregate weight and specific gravity of the concrete 3) To determine the strength of the sulfur-bonded concrete with a maximum age of 28 days.

2. Literature Review

Portland cement concrete (PCC) has been the most widely used concrete in the construction industry. However, PCC has a short service life under some aggressive environments, leading to the need for costly repairs. Several modified sulfur concrete mixtures were prepared using natural aggregates from the northern region of Colombia and sulfur cement by combining sulfur with a modifier to achieve the best performance based on mechanical strength and chemical resistance. To achieve this purpose, an experimental program based on a k-factorial design was used to determine the optimal mix design based on the compressive strength results. The mixture presenting the best results was then examined further with standardized tests to determine its physical, mechanical, and chemical properties (compressive strength, abrasion resistance, bulk density, absorption, and chemical resistance) (compressive strength, abrasion resistance, bulk density, absorption, and chemical resistance). The final results showed that the sulfur concrete mixture is resistant to chemical attack and an outstanding substitute for PCC. The results indicated no significant loss in weight and no relevant variation in compressive strength after the specimens were immersed in sulfuric acid and sulfate solutions. In addition, similar results were obtained for the slabs located in chemical plants whose conditions were assessed during 60 days of exposure [Dugarte, 2019].

The increase in the technologies and concern about the environmental issues in the present world has led to the requirement of a new construction material that does less harm to the environment and utilizes the available waste material. Sulphur concrete is the type of concrete where cement and water are not used; instead, melted sulphur which acts as a binding agent, is used to bind the fine and coarse aggregate and the filler material like fly ash to form a hard concrete. Water absorption, resistance to different chemical environments, and rapid chloride ion penetration tests are done to determine the superiority of sulphur concrete over cement concrete. The result shows that sulphur concrete can be used in areas subjected to heavy moisture content, where there are more acid activities. Strength wise, SC gives a similar result to standard concrete. Another advantage of sulphur concrete is that any fine aggregate can be used as filler in SC since it is a water repellent type of concrete [Mohammed, 2018].

As a new type of building material, SC has corrosion resistance, quick setting, and hardening characteristics. In many fields of construction engineering, it can be applied as a substitute for PCC. Even in some fields, SC is more suitable for application than PCC. However, SC is brittle and shrinks significantly in setting and hardening, so it must modify SC; otherwise, fatal problems may appear insignificant projects. Temperature is an important factor affecting the application of SC because the transformation between allotropes will accelerate with the variation of temperature, resulting in different states of sulfur. Therefore, in SC mixing, temperature control is significant. The use of SC is greatly affected by temperature. Therefore, in the process of forming, transportation, and pouring, with more mature technology, the problem of imperfect forming of SC will be reduced [You, 2021].

Even though Sulfur generally results in weaker and less homogeneous materials, various testing methods concluded that Sulfur Concrete with optimal Sulfur contents delivers compressive, tensile, and flexural strengths higher than cement-based concrete [Mohamed, 2021]. Sulfur concrete has beautiful qualities and various properties such as high strength, corrosion resistance, mechanical strength, impermeability, recyclability, and rapid hardening that have created significant interest in using it. It can be used in dam building, construction of sewer pipes, irrigation canals, concrete piles, piers, beach walls, etc., so that a more significant proportion of cement produced in the country would be used in construction because generally, sulfur concrete cannot be used instead of cement concrete unless in areas with medium and low structural importance or when there is no possibility of using concrete cement. Results indicate that sulfur concrete with the other stuff, covered cement concrete with sulfur-modification, sulfur concrete containing fibre, sulfur concrete with electrolytic residual, and Sulfur concrete with fly ash, depending on the combination of resistance in most cases, have equal to or higher resistance than conventional Sulfur and cement concrete; it is also clarified that sulfur concrete with fly ash has higher pressure resistance than the other compositions [Khademi, 2015].

3. Methodology

The research method used is an experimental method based on calculating the density of concrete specimens and the volume of the mould for sulfur concrete specimens. The steps taken in this experimental research can be seen in the flow chart in Figure 1 below:

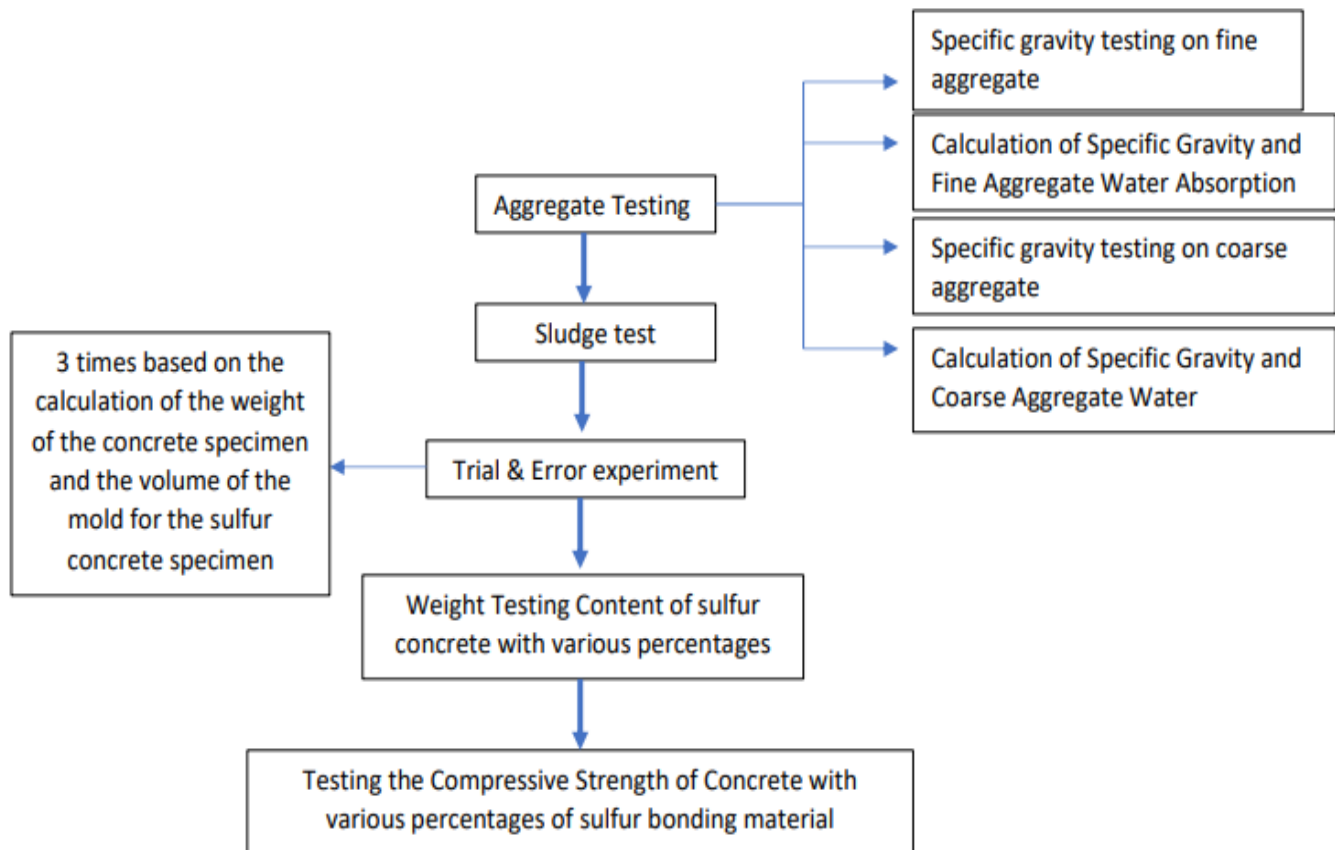


Figure 1. Flow Chart taken in this experimental research

4. Results and Discussion

4.1 Aggregate Testing

4.1.1 Specific Gravity and Water Absorption of Fine Aggregate (Sand)

From the density test on the halo aggregate, it was found that the dry surface density of SSD is 2.62. With this density, the aggregate used can be classified as average because it is still between 2.2 and 2.7. From these data, it can also be seen that the water absorption is 1.53, which means that the ability of the aggregate to absorb water from a dehydrated state to face dry saturation is 1.53.

Table 1. Test Heavy Halos Aggregate Type and Water Absorption

Test	I	II	Flat flat
Heavy SSD Aggregate (grams)	250	250	250
Heavy Aggregate + Water + Pycnometer (grams)	823,5	823,5	823,5
Heavy Aggregate Oven Dry (grams)	246	246,5	246,25
Heavy Pycnometer + Water (grams)	669	669	669
Heavy Type $(B_K / (B + B_{ssa} - B_T))$	2,58	2,58	2,58
BJssd $(B_{SSD} / (B + B_{SSD} - B_T))$	2,62	2,62	2,62
pseudo BJ $(B_K / (B + B_K - B_T))$	2,69	2,68	2,685
Absorption $(\%) ((B_{ssp} - B_K) / B_K \times 100\%)$	1,13	1,92	1,53

4.2 Sand Mud Level

Judging from the Sludge content test, it turns out that the Sludge content for fine aggregate is 1.60, which is higher than the required 5% (SK SNI S - 04 - 1989 - F). So fine aggregate is suitable for use in concrete mixes.

Type Test	Test
Heavy Aggregate (W1 gram)	1000
Heavy aggregate above no. 200 (grams)	1476
Sludge Content $(W_1 \text{ gram} - W_2 \text{ gram}) / W_t \text{ gram} \times 100\%$	1.60

4.3 Specific Gravity and Water Absorption of Coarse Aggregate (crushed stone)

From the density test on coarse aggregate, the best surface dry type of SSD is 2,625; with this type of best, the aggregate used can be classified as an average aggregate because it is still between 2.2 - 2.7. From these data, it can also be seen that the water absorption is 2.04, which means the ability of the aggregate to absorb water from a dehydrated state to face dry saturation is 2.04% of the aggregate weight itself. This water absorption test results are, by what is required, a maximum of 3%.

Table 2. Test of Specific Gravity and Absorption of Coarse Aggregate Water

Test	I	II	Average
Weight (BJ gram)	2005	2337	2171
Heavy Oven Dry (BK gram)	1964	2291.5	2127.75
Heavy in water (BA gram)	1239	2291,5	2127,75
Berat Jenis $(B_K / (B_j - B_A))$	2,5 6	2,`5	2 _g 5A
BJssd $(B_J / (B_1 - B_A))$	2,62	2,63	2,625
BJ semu $(B_K / (B_K - B_A))$	2,71	2,70	2,71
Absorption $(\%) ((B_j - B_K) / B_K \times 100\%)$	2.09	1.99	2.04

4.4 Crushed Stone Mud Level

Judging from the Sludge content test, it turns out that the Sludge content for the coarse aggregate is 0.60, which is greater than the 1 % required (SK SNI S - 04 - 1989 - F). So, coarse aggregate is suitable for use in concrete mixes.

Type Test	Test
Heavy Aggregate (W1 gram)	2500
Heavy aggregate above no. 200 (grams)	2485
Sludge Content (W 1 gram - W2 gram)/ Wt gram x 100%	0.60

4.5 Sulfur Concrete Testing Data and Analysis

In planning this sulfur concrete mixture, a trial and error method is used, based on the calculation of the weight of the concrete specimen and the volume of the mould for the sulfur concrete test object, which is a cube of size 10 x 10 x 10 cm. Aggregate in concrete occupies + 75% of the volume of concrete. Determining the amount of combined aggregate weight based on the volume of the mould used, namely a cube of size 10 x 10 x 10 cm, is as follows:

- 1) The weight of sulfur concrete is estimated to be 2400 kg/m³
- 2) Print volume 10 x 10 x 10 = 1000 cm³ = 0.001 m³
- 3) Weight of test object (W) = Weight of concrete content x Volume of mold = 2400 kg/m³ x 0.001 m³ = 2.4 kg = 2400 gram
- 4) It is assumed that the aggregate in sulfur concrete occupies + 75% of the volume of concrete

4.6 The First Trial & Error

70% of the weight of the test object is used as the total weight of the combined aggregate. Combined weight of aggregate = weight of test object x 70 = 2400 grams x 70 = 1680 grams = 1700 grams. So, 70% as coarse aggregate and 30% fine aggregate from the total combined weight of 1700 grams. Sulfur percentages of 10%, 12.5%, and 15% of the total weight of the combined aggregates are used.

The need for one time mixing of sulfur concrete with a combined aggregate weight of 1700 grams

Table 3. Experiment With Aggregate 1700 Gram

Sulfur		Ag. Rough 70 %	Ag. Fine 30 %	1 time in total stirring
%	gram			
10	170	1190	510	1870
12.5	212.5	1190	510	1912.5
15	255	1190	510	1955

From the composition of the mixture, it turned out that at the time of casting, there was no binding between the aggregates due to the low percentage of sulfur.

4.7 The second trial & error

The addition of the combined aggregate weight from 1800 grams to 1900 grams was 5.26, with a composition of 60% coarse aggregate and 40 fine aggregates. Sulfur percentages were used at 25%, 27.5%, and 30% of the total combined weight of aggregates Material requirements for I times of mixing sulfur concrete with a combined aggregate weight of 1900 grams.

Table 4. Experiment With Aggregate 1900 Gram

Sulfur		Ag. Rough 60 %	Ag. Fine 40 %	1 time in total stirring
%	grams			
25	475	1140	760	2375
27.5	522.5	1140	760	2422.5
30	570	1140	760	2470

The results obtained made it possible to make 3 samples of 10 x 10 x 10 cm specimens for the percentages of 25%, 27.5%, and 30%.

4.8 The Third Trial & Error

Reduction of combined aggregate weight from 1900 grams to 1800 grams, the composition of coarse aggregate is 60%, and fine aggregate is 40. Sulfur percentages of 32.5%, 35%, 37.5%, and 40% of the total combined aggregate weight are used. Material requirements for one time mixing sulfur concrete with a combined aggregate weight of 1800 grams.

Table 5. Experiment with 1800 Gram Aggregate

Sulfur		Ag. Rough 60 %	Ag. Fine 40 %	1 time in total stirring
%	grams			
32.5	585	1080	720	2385
35	630	1080	720	2430
37.5	675	1080	720	2475
40	720	1080	720	2520

From this composition, sulfur concrete with a size of 10 x 10 x 10 cm is produced, which is perfect. The results obtained made it possible to make three samples of 10 x 10 x 10 cm specimens for 32.5%, 35%, 37.5%, and 40%.

4.9 Fill Weight Test

Table 6. Concrete fill weight

Test Object	weight -installment concrete sulfur (kg)	War Volume - sulfur concrete rate (cm ³)	Filling Weight (kg /m ³)
Sulfur concrete 25%	2,236 th most common	1000	2238
Sulfur concrete 27.5%	2,251 th most common	1000	2251.5
Sulfur concrete 30%	2,343 th most common	1000	2342
32.5% sulfur concrete	2,481	1000	2481
35% sulfur concrete	2,493	1000	2493
37.5% sulfur concrete	2,492	1000	2492
40% sulfur concrete	2,512	1000	2512

4.10 Test Strong Press Concrete

Table 7. Test Results Strong Press 25% Sulfur Concrete

Age (days)	Heavy (kg)	LP(cm)	Pmax	Strong Press (kg/cm ²)	Strong Press Average
1	2215	100	190	190	188.5
1	2223	100	187	187	
2	2204	100	178	178	173
2	2231	100	168	168	
28	2237	100	253	253	250,5
28	2235	100	248	248	

Table 8. Test Results Strong Press 27.5% Sulfur Concrete

Age (days)	Heavy (kg)	LP(cm)	Pmax	Strong Press (kg/cm ²)	Strong Press Average
1	2231	100	205	205	202
1	2240	100	199	199	
2	2254	100	210	210	212
2	2251	100	214	214	
28	2265	100	267	267	264
28	2263	100	261	261	

Table 9. Test Results Strong Press 30% Sulfur Concrete

Age (days)	Heavy (kg)	LP(cm)	Pmax	Strong Press (kg/cm ²)	Strong Press Average
1	2343	100	215	215	223
1	2341	100	231	231	
2	2338	100	234	234	226,5
2	2340	100	219	219	
28	2351	100	277	277	272
28	2352	100	267	267	

Table 10. Test Results Strong Press 32.5% Sulfur Concrete

Age (days)	Heavy (kg)	LP(cm)	Pmax	Strong Press (kg/cm ²)	Strong Press Average
1	2478	100	316	316	325
1	2481	100	334	334	
2	2479	100	356	356	338,5
2	2480	100	321	321	
28	2485	100	421	421	429,5
28	2483	100	438	438	

Table 11. Test Results Strong Press 35% Sulfur Concrete

Age (days)	Heavy (kg)	LP(cm)	Pmax	Strong Press (kg/cm ²)	Strong Press Average
1	2488	100	298	298	288
1	2486	100	278	278	
2	2491	100	305	305	302
2	2492	100	299	299	
28	2495	100	397	397	376,5
28	2493	100	356	356	

Table 12. Test Results Strong Press 37.5% Sulfur Concrete

Age (days)	Heavy (kg)	LP(cm)	Pmax	Strong Press	Strong Press
1	2489	100	287	287	282
1	2487	100	277	277	
2	2482	100	293	293	297
2	2478	100	301	301	
28	2491	100	388	388	378,5
28	2494	100	369	369	

Table 13. Test Results Strong Press 40% Sulfur Concrete

Age (days)	Heavy (kg)	LP(cm)	Pmax	Strong Press (kg/cm ²)	Strong Press Average
1	2495	100	285	285	288
1	2491	100	291	291	
2	2489	100	276	276	282.5
2	2493	100	289	289	
28	2499	100	365	365	369
28	2493	100	373	373	

Compressive Strength of Sulfur Concrete

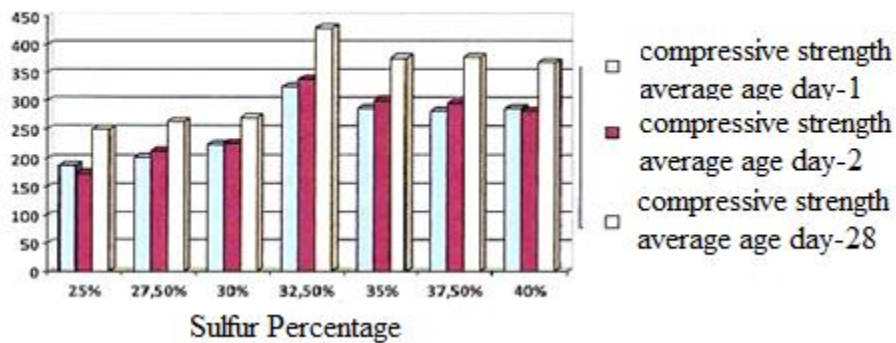


Figure 2. Bar Diagram of Compressive Strength of Concrete with Age 1, 2, and 28 days

Compressive Strength of Sulfur Concrete

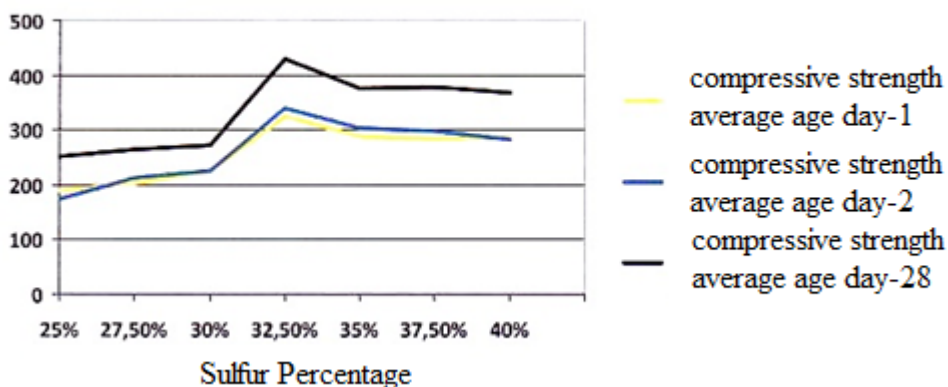


Figure 3. Graph of Compressive Strength Testing for 12 and 28 days

5. Conclusion

Sulfur based composite materials formulated using sulfur polymer cement (SPC) and mineral aggregates are described and compared with conventional portland cement based materials [18]. The results showed that the subsequent analysis might indicate that the aggregate fine and coarse ratio is 40 percent to 60 percent. Design combination sulfur concrete done with try repetition with percentage sulfur 25%, 27.5 %, 30 %, 32.5 %, 35 %, 37.5% and 40 % of heavy aggregate combined and weight type concrete 2400 kg/m³. Strength maximum sulfur concrete 28 days old of 429.5 kg/cm² at the percentage of sulfur 32.5 % and the lowest 250.5 kg/cm² at the percentage of sulfur 25 %. The optimal content of sulfur addition was determined, which makes it possible to

increase the strength of building mixtures by 20-30%. The possibility to use sulfur- modified composite mortar to strengthen the construction [Efremova, 2021]. One of the uses for sulfur which is again being studied, is the cementing ingredient in concrete instead of portland cement. Possible that sulfur concrete will be found helpful in many circumstances. The possible advantages of sulfur concrete combined with forecasts for sustained low sulfur costs will offer a stimulus for aggressive study, development, and usage of this material. Sulfur concrete cannot be assumed to be a generic replacement for portland cement concrete. Sulfur concrete can be utilized mainly for applications not suited to portland cement concrete [Loov, 1974].

References

- [1] Yanita, R. (2020). Semen PCC sebagai Material Green Construction dan Kinerja Beton yang Dihasilkan. *Jurnal Sains dan Teknologi*, 19 (1): 13-18.
- [2] Djamil, B. (2017). Concrete as a Sustainable Construction Material. *Key Engineering Materials*, 744: 196-200.
- [3] Kim, T H., & Chae, C. U. (2016). Environmental Impact Analysis of Acidification and Eutrophication Due to Emissions from the Production of Concrete. *Sustainability*, 8:578-598.
- [4] Miller, S. A. (2020). The role of cement service-life on the efficient use of resources. *Environmental Research Letter*, 15: 1-9.
- [5] Senaratne K. (2017). Recycled Concrete in Structural Applications for Sustainable Construction Practices in Australia. *Procedia Engineering*, 180: 751-758.
- [6] Vroom, A. H. (1998). Sulfur Concrete Goes Global. *Concrete International*, 20(1): 68-71.
- [7] You, X. (2021). Research Progress of the Modification in Sulfur Concrete. *Materials Sciences and Applications*, 12(7): 353-361.
- [8] Lewandowski, M & Kotynia, R. (2018). Assessment of Sulfur Concrete Properties for Use in Civil Engineering. *MATEC Web Conf: 2nd Baltic Conference for Students and Young Researchers*, 219: 1-15.
- [9] Fediuk K. (2020). A Critical Review on the Properties and Applications of Sulfur-Based Concrete. *Materials*, 13: 1-23.
- [10] Mohamed, A M O., & Gamal, M E. (2009). Hydro-mechanical behavior of a newly developed sulfur polymer concrete. *Cement and Concrete Composites*, 31(3): 186-194.
- [11] Jawad, Y A., & Al-Qudah, M. (1994). The Combined Effect of Water and Temperature on the Strength of Sulfur Concrete. *Cement and Concrete Research*, 24(1): 165-175.
- [12] Mohamed, K. (2021). A Review of Sulfur Concrete Properties and Applications. *International Journal of Advanced Research in Science, Engineering and Technology*, 8(9): 18185-18191.
- [13] Szajerski K. (2020). Radiation-Induced Strength Enhancement of Sulfur Polymer Concrete Composites Based On Waste and Residue Fillers. *Journal of Cleaner Production*, 271: 1-71.
- [14] Dugarte, M., Arguelles, G.M., & Torres, J. (2019). Experimental Evaluation of Modified Sulfur Concrete for Achieving Sustainability in Industry Applications. *Sustainability*, 11(70): 1-16.
- [15] Mohammed, S., & Poornima, V. (2018). Strength and Durability Study of Sulphur Concrete with Replaced Fine Aggregate. *Materials Today: Proceedings*, 5(11): 23888-23897.
- [16] Mohamed, K., & Khodair, Y. (2021). A Review of Sulfur Concrete Properties and Applications. *International Journal of Advanced Research in Science, Engineering and Technology*, 8(9): 18185-18191.
- [17] Khademi, A., & Sar, H.I.K. (2015). Comparison of Sulfur Concrete, Cement Concrete, and Cement-Sulfur Concrete and their Properties and Application. *Current World Environment*, 10: 201-2017
- [18] McBee, C.W., Weber, H.H. (1990). Sulphur Polymer Cement Concrete. Proceedings of the Twelfth Annual Department of Energy Low-Level Waste Management Conference(CONF-9008), Idaho National Engineering Laboratory, Idaho Falls, Idaho, 120-141.
- [19] Efremova K. (2021). Sulfur-Modified Composites for Enhancement of Building Foundations. *E3S Web of Conferences*, 247: 1-4.
- [20] Loov, R.E., Vroom, A.H., & Ward, M.A. (1974). Sulfur Concrete-A New Construction Material. *PCI Journal*, 19:86-95.