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Modeling of Mechanical Performance from Concrete Made by Combining Iron Sand and Glass Powder Filler under Hot Water Curing Condition

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ABSTRACT

The proportions of the concrete are critical for obtaining a high-strength, high-quality product. Different concrete grades may support varying loads and have varying ratios. Therefore, the objectivity of this research is to study mechanical performance from concrete treated with iron sand, glass powder, and hot water curing. The level of iron sand and glass powder treatment added to the SNI concrete composition is 2% to 10%, 1% to 5%, (w/w), respectively. The curing time and temperature were applied between 1 hr to 4 hr and 301 K to 343 K. The compressive strength of the concrete was tested on 0, 1, 3, 7, and 28 days after molding using UTM with a combination of linear regression and response surface models for optimization. The addition of iron sand and glass powder to increase the best compressive strength was 10%, 2.45%, respectively. Iron sand treatment of 10% combined with glass powder filler 3.04% was predicted to give the best compressive strength of 32.50 MPa. The compressive strength value of this treatment was 21.78% higher than that of SNI concrete. Treat the curing temperature, curing time, and age of the concrete which gives the best compressive strength (28.33 MPa) with SNI concrete composition of 301 K, 4 days, and 28 days. This research shows that the addition of iron sand, glass powder, and hot water curing to the composition of SNI concrete can increase its compressive strength.

1. INTRODUCTION

The new construction material, high-performance concrete, is a compact solid material with excellent properties. The compressive strength of performance concrete at 28 days can be around 27.5 MPa (SNI 03-2834-2000) [1]. However, the manufactured sand supplied in some regions falls short of the market demand due to the unparalleled level of the construction industry, and its price has also increased. In light of this, there is an urgent need for low-cost materials such as fine aggregate in concrete production. Several materials that have been studied can be used as fillers in concrete, including glass-powder [2-4], iron ore sand [5-7], seashell [8-10], and so on.

One of the low-cost materials widely available and have not been utilized, especially in Indonesia, is sand iron and glass powder waste. Several research results indicate that these two materials can be a substitute for fine aggregate from the constituent materials of concrete. Vasudevan [11] tested the concrete mixed with sand iron and found the best composition for the concrete admixture of 5% (w/w) with a compressive strength of 16.05 MPa. De Moura et al. [12] found that the highest compressive strength at 28 days was 23.0 MPa for concrete with 34% glass powder. Another study by Boukhelf et al. [13] explained that the addition of glass powder could increase the compressive strength of concrete in the range of 36 MPa to 38 MPa at 28 days. Jain et al. [14] combined a mixture of granite and glass powder to concrete and obtained the best composition at a combination of 15% (w/w) glass powder and 30% (w/w) granite powder and resulting in compressive strength of 36.85 MPa. Unfortunately, until now, no research has investigated the combination of these two materials to increase the compressive strength of concrete.

Air curing treatment can increase the compressive strength of concrete. As done by Peng et al. [15] tested the effect of temperature (200℃ to 250℃) and curing time of concrete (1 hr to 3 days) on the compressive strength of concrete. Unfortunately, the choice of treatment level in this experiment was inefficient due to the energy required to produce high temperatures and too long curing time. Another study by Hamza et al. [16] used water curing temperature of 40℃ and obtained compressive strength at 28 days around 40 MPa. Ibrahim et al. [17] also investigated concrete under hot weather conditions at water curing temperature of 40℃ and found its compressive strength at 28 days around 24.5 MPa to 28.3 MPa. However, this research still uses a long curing time treatment level so that it is still not efficient to be carried out, especially by industry.

In order to meet the design criteria, the first step was to thoroughly study the composition properties of concrete to determine if this mixing composition is enough to achieve a mechanical performance from concrete. Complete characterization and specific tests for aggregates in concrete were performed [18-20]. Then, specific tests for concrete were developed. Following that, the next stage was to investigate when concrete behavior is substituted individually and when both are substituted together.

Until now, to the best of our knowledge, no research has researched the effect of adding iron sand, glass powder, and their combination and treatment hot water curing on the compressive strength of concrete. The proportion of the concrete is significant to obtain high strength and good quality concrete. Different grades of concrete can carry other loads and have different ratios. Proper planning for each material in the design is critical to avoid under or over-design [21]. Therefore, the objective of this study was to investigate and model the effect of iron sand, glass powder, and hot water curing and their combination on the quality of concrete indicated by compressive strength.

2. MATERIAL AND METHOD

2.1 Physical properties of materials

This study's concrete constituent materials consisted of sand, gravel, iron sand and glass powder, and cement. All materials used in this study were obtained from material stores located in Lampung Province, Indonesia. The physical properties of the materials used are presented in Table 1.

The procedure for making a standard concrete mix plan in this study follows the Indonesian National Standard (SNI) no 03-2834-2000 with the specifications presented in Table 2. Furthermore, the composition of this SNI concrete mixture is used as a reference as a comparison with the treatment of other types of concrete used in this study. The mechanical performance that was compared for each concrete tested was in the form of compressive strength (MPa) which was measured using the Universal Testing Machine (UTM) RTF 1350 (capacity 250 kN). The cylindrical molded concrete has a diameter and height of 100 mm and 200 mm, respectively. The selection of the shape and size of this concrete test is based on the generality of several studies that use this shape as a reference in concrete testing [22-24]. In addition, the cylindrical shape of the concrete will provide a more uniform distribution of load during compression tests compared to other forms [25]. Age testing of concrete follows the ASTM C39 standard [26-28].

Table 1. Physical properties of material

Physical properties	Material type				Unit
	Sand	Gravel	Iron sand	Glass powder	
Bulk specific gravity	2.61 ± 0.0057	2.52 ± 0.0035	4.35 ± 0.0071	2.48 ± 0.0028	-
Bulk SSD specific gravity	2.64 ± 0.0049	2.57 ± 0.0014	4.37 ± 0.0021	2.50 ± 0.0007	-
Apparent specific gravity	2.68 ± 0.0042	2.65 ± 0.0007	4.47 ± 0.0127	2.54 ± 0.0064	-
Absorption	0.92 ± 0.0148	1.95 ± 0.0608	0.61 ± 0.1004	0.91 ± 0.1442	%
Weight per volume	1.47 ± 0.0396	1.31 ± 0.1053	2.41 ± 0.0601	n/a	gr/cm^3
Sludge content	0.44 ± 0.1273	0.58 ± 0.0354	n/a	n/a	%

Table 2. Normal concrete composition according to SNI

Description	Data	Unit
Water cement ratio	0.51	-
Amount of cement	373,000	g
Amount of water	190	l
Amount of coarse aggregate	1839	g
Amount of fine aggregate (sand)	1080	g

2.2 Composition of concrete with iron sand

The level of treatment of adding iron sand to the concrete composition in this study was 0, 2, 4, 6, 8, 10% (w/w) of the amount of fine aggregate (sand) according to SNI. The optimization treatment of adding iron sand to the SNI concrete composition is done by the linear regression method.

2.3 Composition of concrete with glass powder filler

The treatment level of adding glass powder filler to concrete in this study was 0, 1, 2, 4, and 5% of the amount of fine aggregate (sand) according to SNI. The linear regression method was used to optimize the glass powder filler treatment of the SNI concrete composition. The optimum value is obtained by deriving the linear regression equation.

2.4 Composition of iron sand combined with glass powder filler to concrete

The iron sand treatment used in this experiment was the best for yielding compressive strength from section 2.2. Furthermore, glass powder as a filler used is 1, 2, 4, and 5% (w/w) of the amount of fine aggregate (sand) according to SNI. The optimization treatment composition of iron sand combined with glass powder filler to concrete is done by linear regression method [29-31]. The optimum value is obtained by deriving the linear regression equation.

2.5 SNI of concrete composition under hot water curing condition

Hot water curing treatment of concrete with SNI composition was carried out at five temperature levels, namely 301, 313, 323, 333, and 343 K. The temperature of 301 K was the ambient temperature for the conditions of all experiments carried out. The curing period used for each temperature is 1, 2, 3, and 4 hours. The compressive strength of the concrete was measured at the age of 0, 1, 3, 7, and 28 days. The response surface method is used to optimize SNI concrete composition under hot water curing conditions. This method has been widely reported and used to optimize concrete materials' treatment design and composition [32-34]. The optimum value of the treatment was obtained with a goal for each treatment in the range condition and yield (compressive strength) at the maximum condition.

3. RESULT AND ANALYSIS

3.1 Effect of iron sand on the compressive strength of concrete

The compressive strength of concrete with and without the addition of iron sand at various ages of concrete is presented in Figure 1. The addition of iron sand to concrete composition causes compressive strength of concrete to change along with increase in age of concrete. Concrete enriched with iron sand as much as 10% (w/w) can increase its compressive strength by 13.97% (30.42 MPa) compared to the composition of SNI concrete. The compressive strength with the addition of 10% sand iron from this study was better than the results of Vasudevan [11] which obtained a compressive strength of 16.05 MPa at a 5% sand iron mixing composition.

The compressive strength of the concrete with the addition of iron sand is presented in Figure 2. The compressive strength was analyzed at the age of 28 days of concrete. Iron sand is known to increase the compressive strength of concrete following a quadratic equation. The quadratic equation of the percentage addition of iron sand on compressive strength is presented in Equation 1. Each addition of iron sand of 2, 4, 6, 8, and 10% (w/w) gives a change in the compressive strength of concrete (negative its means decreasing, positive its means increasing) respectively -9.02%, -1.54%, -0.76%, 5.30%, 13.97% compared to SNI concrete. Optimization of the addition of iron sand to maximize the compressive strength of the concrete was analyzed using Equation 1 and obtained about 10%.

$$\sigma_{is} = 0.0986 C_{is}^{2} - 0.5528 C_{is} + 26.19 \qquad (1)$$

where, σ_{is}- compressive strength with add iron sand (MPa), C_{is}-iron sand composition (%).

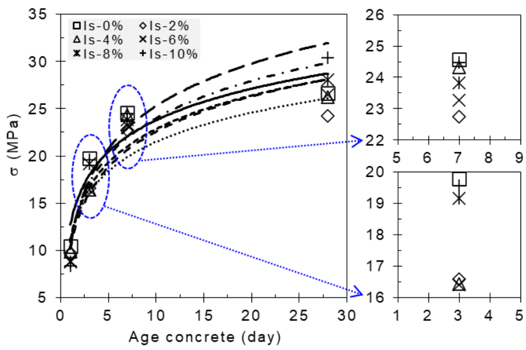

Figure 1. Ages vs. compressive strength (σ) of concrete with and without iron sand substitution

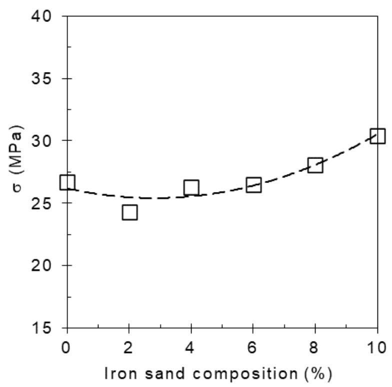

Figure 2. Compressive strength (σ) of concrete with and without iron sand substitution

3.2 Effect of glass powder filler to concrete

The compressive strength of concrete with the addition of glass powder as a filler at several concrete ages is presented in Figure 3. The addition of glass powder as a filler in the concrete composition makes the compressive strength of the concrete change in the range of 2.1% to 10.9% compared to SNI concrete, along with the increase in the age of the concrete. Concrete filled with glass powder 2% (w/w) provides the greatest compressive strength (32.49 MPa) compared to the additional percentage of other glass powder. However, concrete with glass powder filling still provides better compressive strength than SNI concrete composition.

The compressive strength of concrete with glass powder filler is presented in Figure 4. The compressive strength was analyzed at 28 days of concrete age. The quadratic equation of the percentage of filler glass powder on compressive strength is presented in Eq. (2). Each addition of glass powder of 1, 2, 4, and 5% (w/w) changes the compressive strength of concrete by 10.9%, 21.75%, 8.23%, and 2.08%, respectively, compared to SNI concrete. The optimization of glass powder filler to strengthen the compressive strength of concrete was analyzed using Eq. (2) and obtained about 2.45%. This equation uses the concrete age of 28 days after molding (specific equation). For other concrete ages, this equation can be changed according to the coefficients of the formed equation.

$$\sigma_{GPF} = -0.7563 C_{GPF}^{2} + 3.7054 C_{GPF} + 27.135 \qquad (2)$$

where, σ_{GPF} - compressive strength with add glass powder (MPa), C_{GPF} - glass powder composition (%).

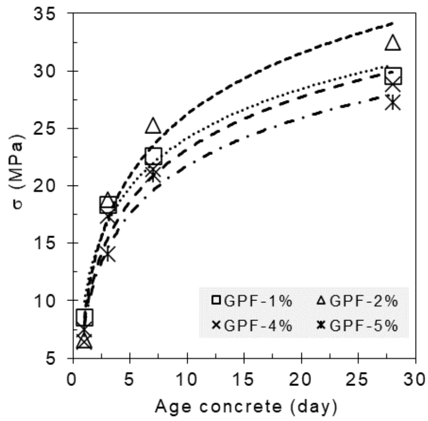

Figure 3. Ages vs. compressive strength (σ) of concrete with glass powder filler

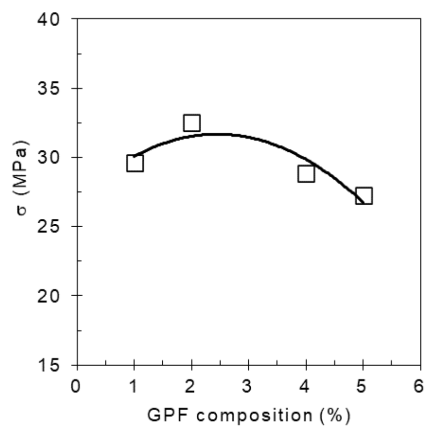

Figure 4. Compressive strength (σ) of concrete with waste glass powder filler

3.3 Effect of iron sand combined with glass powder filler to concrete

The compressive strength of iron sand combined with glass powder filler to concrete at several ages is presented in Figure 5. In the previous experiment (section 3.1), it was found that the optimal addition of iron sand to increase compressive strength was 10%. The optimal result from iron sand is then combined with glass powder as a filler to increase the compressive strength. The results show that iron sand combined with glass powder filler can increase compressive strength in the range of 15.26% to 21.23% compared to SNI concrete. Iron sand combined with glass powder filler can increase compressive strength in the range of 1.13% to 6.37% compared to concrete with 10% iron sand. In addition, iron sand combined with glass powder filler can increase compressive strength in the range of 3.93% to 9.31% compared to concrete-filled with glass powder by 2%.

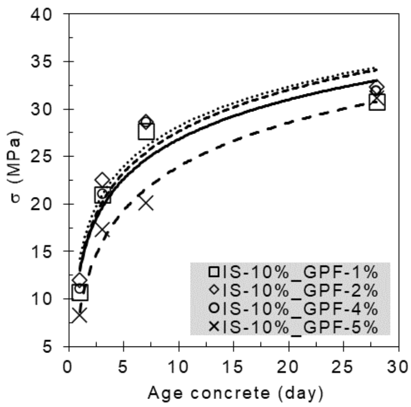

Figure 5. Ages vs. compressive strength (σ) of concrete with 10% of iron sand and some level glass powder filler

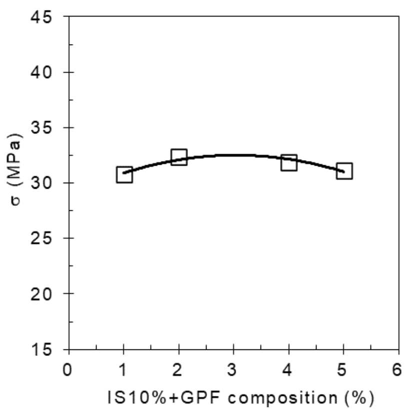

Figure 6. Compressive strength (σ) of concrete with 10% of iron sand and some level glass powder filler

The compressive strength of iron sand combined with glass powder filler to concrete is presented in Figure 6. The quadratic equation of the percentage addition of iron sand on the compressive strength is shown in Equation 3. Each addition of glass powder is 1, 2, 4, and 5% (w/w), and iron sand by 10% will change the compressive strength of concrete by 15.26%, 21.23%, 19.46%, and 16.73%, respectively compared to SNI concrete. In addition, the addition of glass powder of 1, 2, 4, and 5% (w/w) and iron sand of 10% will give a change in the compressive strength of concrete by 1.13%, 6.37%, 4.82%, and 2.42% respectively compared to with concrete that is only treated with the addition of 10% iron sand. Finally, the addition of glass powder of 1, 2, 4, and 5% (w/w) and iron sand of 10% will give a change in the compressive strength of concrete by 3.93%, 9.31%, 7.71%, and 5.25%, respectively compared to concrete which is only treated with 2% glass powder filling. The optimization of iron sand combined with glass powder filler to strengthen the compressive strength of concrete was analyzed using Equation 3 and obtained about 3.04%.

$$\sigma_{IG} = -0.3869 C_{IG}^{2} - 2.3523 C_{IG} + 28.929 \quad (3)$$

where, σ_{IG}- compressive strength with iron sand combined with glass powder filler (MPa), C_{IG}-iron sand combined with glass powder filler composition (%).

3.4 Compressive strength of SNI concrete under hot water curing condition

The compressive strength of SNI concrete under hot water curing conditions under temperature treatment and age of concrete is presented in Figure 7. However, it was found that an increase in compressive strength of SNI concrete was due to curing temperature treatment. The curing temperature range of 301 K to 343 K has not significantly affected the compressive strength of SNI concrete. On the other hand, the compressive strength of concrete will increase with the increasing age of the concrete from the concrete age 0 to 7 days after molding. However, after seven days, it is assumed that the compressive strength of the concrete will decrease until day 21. This may be due to dehydration of the concrete to its lowest limit. After exceeding 21 days, the concrete can recover and maintain its strength in a more stable condition on the 28th day. This shows that the concrete must be given a period to reach the required strength after molding [35]. Therefore, the best treatment is to give the curing temperature at 301 K, and the test is carried out at the age of 28 days of concrete.

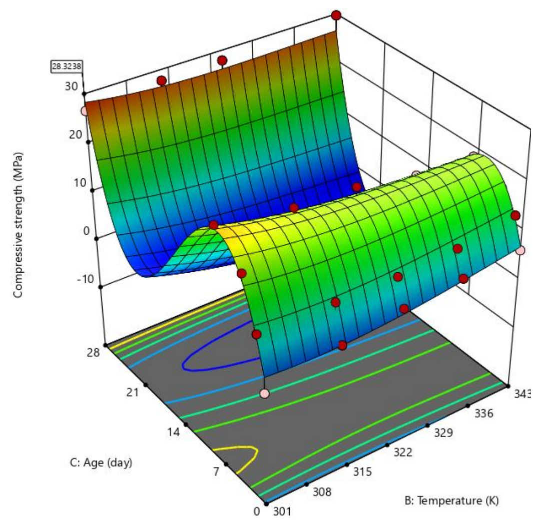

Figure 7. Effect of temperature and age on compressive strength (σ) of concrete SNI

The compressive strength of SNI concrete under hot water curing conditions under treatment of curing time and age is presented in Figure 8. Increasing the curing time by about 1 to

4 hours significantly increases the compressive strength of SNI concrete. Likewise, with the age of concrete, when testing its compressive strength. Therefore, the best treatment is to give a curing time of 4 hours, and the test is carried out at the age of 28 days.

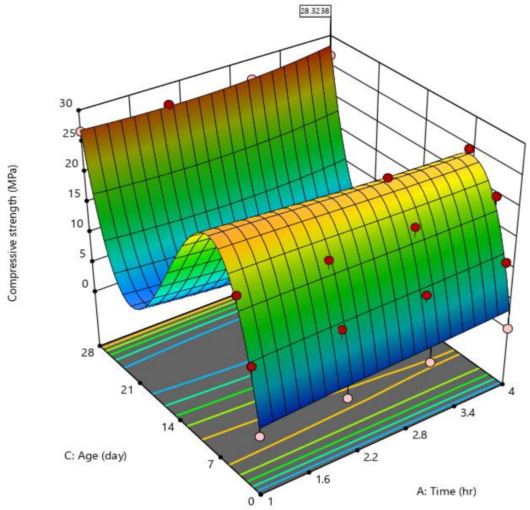

Figure 8. Effect of curing time and age on compressive strength (σ) of concrete SNI

The compressive strength of SNI concrete under hot water curing conditions at curing time and temperature is presented in Figure 9. Increasing curing time will increase the compressive strength of SNI concrete. On the other hand, the curing temperature does not significantly influence the increase in compressive strength. Therefore, the best treatment is to give a curing time of 4 hours and a curing temperature of 301 K.

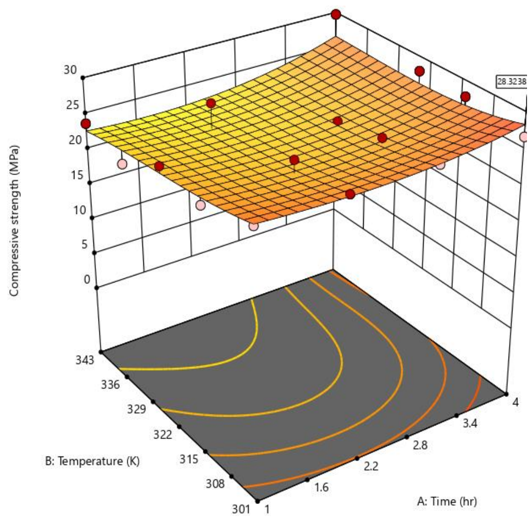

Figure 9. Effect of curing time and temperature on compressive strength (σ) of concrete SNI

The results of the variance analysis from the curing temperature, curing time, and age on the compressive strength of SNI concrete are presented in Table 3. The results of this analysis can show that the three treatments in this test (curing temperature, curing time, and age) have a significant effect ($p < 0.05$) on compressive strength [36-38]. The 0.05 and 0.01 p-values were utilized to determine the significance of each treatment. The treatment level of curing temperature, curing time, and age of 301 K, 4 hr, and 28 days, respectively, has provided the optimum compressive strength of SNI concrete of 28.33 MPa.

Table 3. ANOVA compressive strength of SNI concrete under hot water curing condition

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	6551.21	19	344.80	129.29	<0.0001
Time (A)	6.96	1	6.96	2.61	0.1101
Temperature (B)	52.89	1	52.89	19.83	<0.0001
Age of concrete (C)	220.47	1	220.47	82.67	<0.0001
AB	4.66	1	4.66	1.75	0.1901
AC	0.0005	1	0.0005	0.0002	0.9895
BC	57.72	1	57.72	21.64	<0.0001
ABC	0.1901	1	0.1901	0.0713	0.7901
Residual	213.36	80	2.67		
Cor Total	6764.57	99			

4. CONCLUSIONS

Effect of iron sand, glass powder as filler, and hot water curing and their combination on the quality of the concrete as indicated by the compressive strength has been carried out and modeled. Concrete enriched with iron sand as much as 10% (w/w) can increase its compressive strength by 13.97% (30.42 MPa) compared to the composition of SNI concrete. Concrete filled with glass powder as much as 2% (w/w) can increase its compressive strength by 21.75% (32.49 MPa) compared to the composition of SNI concrete. Concrete enriched with iron sand as much as 10% (w/w) and filled with glass powder as much as 3.04% (w/w) can increase its compressive strength by 21.78% (32.50 MPa) compared to the composition of SNI concrete. The curing temperature, curing time, and concrete age of 301 K, 4 hr, and 28 days gave the optimum compressive strength (28.33 MPa) with SNI concrete composition. This study shows that the substitution of the amount of fine aggregate in the SNI concrete composition with iron sand, glass powder, and hot water curing and their combination can increase the compressive strength of the concrete.

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