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The Influence of Industrial Steel Waste on Slump Test and Compressive Strength in Eco-Friendly Concrete Fabrication

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Abstract: This study evaluated the suitable percentage of replacing natural coarse aggregate (crushed granite) with wasted Zinc Aluminum (Zincalume) generated from metal roofing fabrication industry to produce G35 grade eco–friendly concrete. Design mix for the wasted Zincalume substitution with crushed granite was prepared at 10%, 15% and 20% where the control mix specimen used as reference for mechanical strengths comparison. The mechanical strengths were observed with the increasing of curing age, but the strengths reduced with the increment of wasted Zincalume in the mixture. An amount of 10% of Zincalume substitution gave the optimum mechanical strength values. Acid – base reaction between cement and Zincalume coating in the concrete mixture, generated hydrogen gas, which reduced the compressive strength. The higher percentage of Zincalume in the concrete mixture, the weaker mechanical strengths were obtained. By recycling the steel waste, the eco – friendly concrete encourages to protect environment and enhance the economy growth.

Keywords: Coarse aggregate, compressive strength, sustainable development, wasted coated steel

1. Introduction

Promotion of a sustainable environment is a major concern in the current era, as preserving the environment for future generations seems to be extremely important. Goal 12, Responsible Consumption and Production was to ensure sustainable consumption and production patterns, which targeted the substantially reduction of waste generation, through prevention, reduction, recycling, and reuse, by strengthening the scientific and technological capacity to move towards more sustainable patterns of consumption and production (Pradhan et al., 2017; Stafford-Smith et al., 2017). A systematic structure was needed to reduce the waste produced by manufacturing companies, without leaving anyone behind (Diaz-Sarachaga et al., 2018).

Increased production rates of iron and steel promoted economic wealth. However, they imposed challenges toward sustainable development, due to emissions associated with iron and steelmaking, and increasing usage of resources (Bali et al., 2019). To satisfy the human greed to maximize profit, natural resources were exploited, which have led to its extinction. The processes involved in recycling of wasted steel are tedious. Molten steel needs a critically high temperature of about 1450–1550 °C. Water quenching is a traditional heat recovery technology, which uses cold water to cool down slag. However, this technology consumes a huge amount of water, yet fails to recover the sensible heat of the slag (X. Q. Wang et al., 2020). Some researchers identified wasted steels, which can stay in the environment, and will

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have prolonged contact with environmental components, such as soil and deep water. Subsequently, it might promote the release of dangerous substances for both human health, and the environment (Primavera et al., 2016). The leachate (soaked water from the solid waste) produced from heavy metal is unavoidable, especially in developing countries, which forms emulsion based liquid and (Jesic et al., 2019) flow into water streams involved in the daily usage of the communities (Jayanthi et al., 2016). Studies show that heavy metals can be classified as substantial pollutants due to the high density, even at low concentrations, which can be highly toxic.

Besides being affected by wasted metals in the environment, the coarse aggregate harvested from rock quarries is not an insignificant issue to be overlooked. Pollution from quarries needs to be handled discreetly without compromising human health (Sairanen & Rinne, 2019). In terms of reducing the above-mentioned issues, the replacement of partial coarse aggregates with that of industrial waste has been studied by various researchers. Ceramic waste, recycled concrete aggregates and e-plastic waste, are some of the materials used to replace coarse aggregates partially, for a sustainable environment (Khalid et al., 2017; Sabău & Vargas, 2018). Specifically, for steel waste, it was found that most of the studies were conducted using steel slag, which had an almost similar morphology with that of natural coarse aggregates (Palankar et al., 2016; Venkatesh et al., 2017). Various research works have been conducted to replace coarse aggregate with steel slags, and positive outcomes have been identified (Saxena & Tembhurkar, 2018; S. Wang et al., 2020). However, less research has been conducted on substituting coated steels for that of coarse aggregates.

To reuse this wastage into useful products, this research has been conducted. Coated steels which mainly used in roofing and wall cladding industry as a support in buildings were used for this research studies. In this study, the wastage was reused as a replacement of coarse aggregate to produce G35 concrete. In this research, the wasted coated steel used as substitution for crushed granite has flat surface structure and coated with multi - layer resin composition at both side of coated steel surface. The objectives of this study are to determine the suitability of wasted coated steel, partial substitution of coarse aggregate in concrete fabrication and identify the possibility to produce eco-friendly concrete which prevent the factory's wasted coated steel from entering to the environment through landfills. This is in line with Sustainable Development Goal Twelve (SDG12) for reducing wastes generation through prevention, reduction, re – use, and recycling.

2. Materials and Methods

2.1 Material Preparation

The materials used in this study consisted of tap water, cement, fine aggregates, coarse aggregates, and wasted coated steel as partial replacement of coarse aggregate. Ordinary Portland Cement (OPC) has grade strength of 42.5N which was adequate of binding other ingredients for solidifying concrete was used (YTL Cement, 2017). The fine aggregate used in this study was river sand with a range of 4.75mm to 75μm particles size to fill the voids in concrete to improve the strength. Crushed granite with 20mm particle size was used as coarse aggregate to act as structural filler and occupying majority volume of the concrete to increase the strength and workability purposes. The wasted coated steel, which used as partial substitution of coarse aggregate was steel coated with zinc/aluminium layers, protected with resin coating thickness of 0.05mm on both top and bottom surface (McKenzie, 2018) were precut to 20mm x 20mm. All the measurements are following British Standard and American Standards for Testing and Measurements, ASTM.

2.2 Mixing of Concrete

Concrete grade, G35 was chosen for this study referring to the concrete's base strength on 28th day of curing process which expected to achieve 35 MPa. Table 1 shows the material proportion for mix design. Amount of each material for the concrete mixing was weighted according to the mould volume. Table 2 shows the components used in concrete design mix for cube mould.

Table 1 - Materials fraction used for concrete G35

Material	Proportion (kg/m^3)
Water	230
Cement	430
Fine Aggregate	611
Coarse Aggregate	752

Table 2 - Concrete design mix materials weightage for cube mould's main test

Material	Weightage (kg)

	0%	10%	15%	20%
Cement	1.45	1.45	1.45	1.45
Tap water	0.78	0.78	0.78	0.78
Fine aggregate	2.06	2.06	2.06	2.00
Coarse aggregate – crushed granite	2.54	2.29	2.16	2.03
Coarse aggregate – wasted Zincalume	0.00	0.25	0.38	0.51

2.3 Preliminary test – Slump test

Slump test was conducted to determine true slump to continue with compressive strength test. The slump mould was filled in three stages, and at the top layer, once the compacting process done, the excessive concrete mix was removed from the mould. Later, the slump mould was lifted slowly upward in the vertical direction. The plasticity and cohesiveness properties are essential to determine the slump type. A true slump must be stable, and symmetrical to the mould. Unstable concrete mixing can lead to formation of shear slump, or collapse slump (Tuan et al., 2021).

2.4 Compressive Strength Tests

The ability of hardened concrete to withstand maximum compressive load was determined through compressive strength test. Substitution of the wasted Zincalume were kept at 10%, 15% and 20% for 1 day, 7 days, 14 days, 21 days and 28 days over the period of curing age (British Standard, 2019b). Concrete specimens were cured by air and water, of which the day 1 concrete mixture was cured by air. Meanwhile, specimen for day 7 to day 28 were cured in water. Three sample strengths were tested for each mixed batch to determine the average strength of the hardened concrete.

Cube shaped concrete specimen was used to test the compression load using compression testing machine, where the reading was taken for all mixed batches until the compression reaches the failure point. Fig. 1 shows the procedures of carrying out a compressive strength test for hardened concrete.

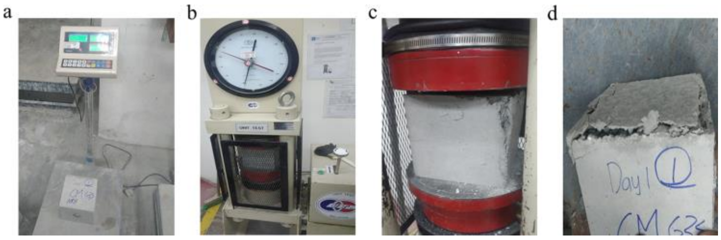

Fig. 1 - (a) Weighing of hardened concrete; (b) Compressive strength machine with load cell; (c) Specimen load test; (d) Specimen failure point of load test

3. Results and Discussion

3.1 Slump Test

Fig. 2 represents the slump height values of freshly mixed concrete for a few batches. The specification for this test result ranged from 60 mm to 180 mm (British Standard, 2019a). The increasing graph trend indicates that the slump height value was directly proportional to the increment of waste Zincalume in the concrete mixture. The water – cement ratio for this study was at 0.53. Compared to crushed granite, the Zincalume has an extremely low angular shape, which increased the workability of the concrete specimen (Yu et al., 2016).

The water absorption of Zincalume was relatively lower than the natural crushed granite, which increased water retention in concrete mixture for higher waste Zincalume content. This caused the water – cement ratio to be higher and the slump value increased accordingly. True slumps were obtained for all batches of the concrete mix, as the workability of the concrete increased with the addition of waste Zincalume in the mixture. No collapse slump or shear slump were obtained during this test.

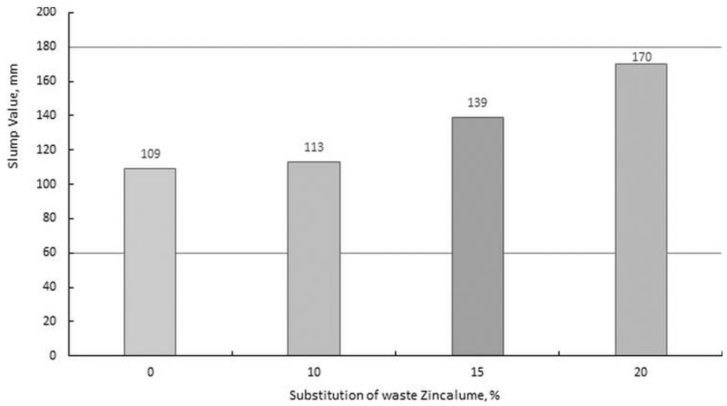

Fig. 2 - Slump height results for freshly mixed concrete with multiple percentage of Zincalume replacement

3.2 Compressive Strength Tests

Fig. 3 shows the mechanical strength across various testing periods, from day 1 to day 28, for concrete batches with 10%, 15% and 20% waste Zincalume substitution, with crushed granite. The compressive strength increased due to the concrete aging process and displayed a continuing decrease in workability of the partially replaced coarse aggregate concrete specimen when the amount of waste Zincalume increased. The 35 MPa targeted strength of G35 concrete on 28th day of water curing was obtained for control mix specimen with the compressive strength achieved at 36.16 MPa, which is 3.3% higher than projected mechanical strength.

For the 10% Zincalume replacement, the obtained mechanical strength was 34.80 MPa, which was 99.43% of the targeted compressive strength value. This value was acceptable, as the expected outcome needed to be at 99% comparatively with that of the base concrete strength, which is 35 MPa (Assefa & Dessalegn, 2019). There was an increase in strength by 6-fold on day 28, compared to day 1 curing for the 10% substitution sample. This was because the day 1 specimen was still wet and weak. The same trend was observed for another percentage of the wasted Zincalume replacement from day 1 to day 28, but the sudden strength decline was detected for the wasted Zincalume substitution 15%, and onwards.

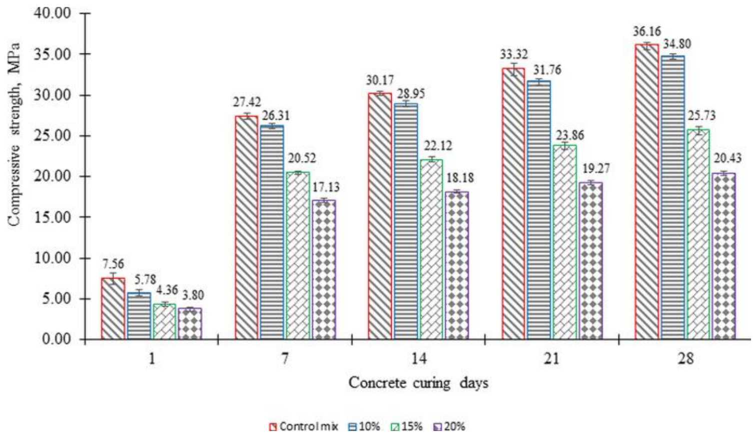

Fig. 3 - Compressive strength tested for (a) day 1; (b) day 7; (c) day 14; (d) day 21; (e) day 28

The main crack was observed on the edge of the specimen and stretched towards the middle point of the sample. This indicates that the wasted Zincalume had bound well in the mixture, as seen at the yellow emphasized circle, to form a rigid concrete structure. Chemical reaction between the cement (alkali, $-OH^{-}$) and the Zincalume coating (Aluminium, Al^{3+}) generated hydrogen gas, H_2 which caused swelling in the concrete, and reduced the compressive strength. The higher the amount of Zincalume added, more hydrogen gas generated through the chemical reaction and weakened the material binding in concrete (Alzubaidi, 2017).

Equation 1 shows the chemical reaction, where the hydrogen gas released has an adverse impact to the compressive strength. Except for 10% replacement concrete with Zincalume, other mixes of the concrete have not met the compressive strength test. Hence, it is not advisable to run a mass production with 15% and 20% mixtures.

$$(OH^{-}) + (Al^{3+}) = Al_2O_3 + H_2O + H_2\,(gas) \quad (1)$$

4. Conclusion

The results obtained showed that the 10% wasted Zincalume substitution with crushed granite gave an optimum compressive and splitting tensile strengths. The mechanical strengths were observed to display a downward trend when the percentage of Zincalume increased beyond 15% in the concrete mixture. The morphology of Zincalume and the chemical reaction between the cement and the Zincalume coating in the concrete mixture weakened the strengths. Recycling steel wastes help to reduce the adverse effects on human health, the environment, and the socio – economy.

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References

Alzubaidi, R. (2017). Recycling of Aluminum Byproduct waste in concrete production. Jordan Journal of Civil Engineering, 11(1), 15–29.

Assefa, S., & Dessalegn, M. (2019). Production of lightweight concrete using corncob ash as replacement of cement in concrete. American Journal of Civil Engineering, 7(1), 17–20.

Bali, N., Panta, M. P., & Antelo, M. (2019). Sustainable performance-oriented production practices in the Indian iron and steel industry: An empirical investigation. Journal of Cleaner Production, 226, 379–391.

British Standard. (2019a). BS EN 12350-2:2019 Testing fresh concrete. Slump test. London, UK: British Standard Institution.

British Standard. (2019b). BS EN 12390-3:2019 Testing hardened concrete. Compressive strength of test specimens. London, UK: British Standard Institution.

Diaz-Sarachaga, J. M., Jato-Espino, D., & Castro-Fresno, D. (2018). Is the Sustainable Development Goals (SDG) index an adequate framework to measure the progress of the 2030 Agenda? Sustainable Development, 26(6), 663–671.

Jayanthi, B., Emenike, C. U., Agamuthu, P., Simarani, K., Mohamad, S., & Fauziah, S. H. (2016). Selected microbial diversity of contaminated landfill soil of Peninsular Malaysia and the behavior towards heavy metal exposure. Catena, 147, 25–31.

Jesic, D., Sovilj-Nikic, S., Kandeva, M., Kalitchin, Z. H., Kovac, P., & Mirjanic, S. (2019). Possibility solutions for disposal of wasted metalworking. Journal of Environmental Protection and Ecology, 20(1), 439–446.

Khalid, F. S., Azmi, N. B., Sumandi, K. A. S. M., & Mazenan, P. N. (2017). Mechanical properties of concrete containing recycled concrete aggregate (RCA) and ceramic waste as coarse aggregate replacement. AIP Conference Proceedings, 3–5 April, 020079.

McKenzie, R. (2018). BlueScope Steel Limited (BSL). Equity, 32(3), 11.

Palankar, N., Shankar, A. U. R., & Mithun, B. M. (2016). Durability studies on eco-friendly concrete mixes incorporating steel slag as coarse aggregates. Journal of Cleaner Production, 129, 437–448.

PRADHAN, P., Costa, L., Rybski, D., Lucht, W., & Kropp, J. P. (2017). A systematic study of Sustainable Development Goal (SDG) interactions. Earth's Future, 5(11), 1169–1179.

Primavera, A., Pontoni, L., Mombelli, D., Barella, S., & Mapelli, C. (2016). EAF slag treatment for inert materials' production. Journal of Sustainable Metallurgy, 2(1), 3–12.

Sabău, M., & Vargas, J. R. (2018). Use of e-plastic waste in concrete as a partial replacement of coarse mineral aggregate. Computers and Concrete, 21(4), 377–384.

Sairanen, M., & Rinne, M. (2019). Dust emission from crushing of hard rock aggregates. Atmospheric Pollution Research, 10(2), 656–664.

Saxena, S., & Tembhurkar, A. R. (2018). Impact of use of steel slag as coarse aggregate and wastewater on fresh and hardened properties of concrete. Construction and Building Materials, 165, 126–137.

Stafford-Smith, M., Griggs, D., Gaffney, O., Ullah, F., Reyers, B., Kanie, N., Stigson, B., Shrivastava, P., Leach, M., & O'Connell, D. (2017). Integration: the key to implementing the Sustainable Development Goals. Sustainability Science, 12(6), 911–919.

Tuan, N. M., Hau, Q. Van, Chin, S., & Park, S. (2021). In-situ concrete slump test incorporating deep learning and stereo vision. Automation in Construction, 121, 103432.

Venkatesh, G., Gopal, K., Nandhini, M., Pavithra, V., & Vignesh, M. (2017). Experimental Investigation On Replacement of Magnetic Water And Partial Replacement Of Steel Slag By Coarse Aggregate In Concrete. International Research Journal of Engineering and Technology (IRJET), 4(3), 2456–2460.

Wang, S., Zhang, G., Wang, B., & Wu, M. (2020). Mechanical strengths and durability properties of pervious concretes with blended steel slag and natural aggregate. Journal of Cleaner Production. https://doi.org/10.1016/j.jclepro.2020.122590.

Wang, X. Q., Tao, Z., & Hassan, M. K. (2020). Post-fire behaviour of high-strength quenched and tempered steel under various heating conditions. Journal of Constructional Steel Research, 164, 105785.

YTL Cement. (2017). YTL Cement Orang Kuat High Strength Cement Specifications, p. 2.

Yu, X., Tao, Z., Song, T.-Y., & Pan, Z. (2016). Performance of concrete made with steel slag and waste glass. Construction and Building Materials, 114, 737–746.