P-ISSN : 2598-1277
E-ISSN : 2621-3966

JOURNAL OF GREEN SCIENCE AND TECHNOLOGY

DEVELOPMENT OF ECO-FRIENDLY MORTAR UTILIZING INDUSTRIAL WASTE

M. Afif Shulhan*, Zainul Faizien Haza*, Maris Setyo Nugroho**

*) Civil Engineering Department, Universitas Sarjanawiyata Tamansiswa, Yogyakarta, Indonesia
**) Civil Engineering and Planning Department, Yogyakarta State University, Indonesia

Corresponding author: afifs@ustjogja.ac.id

ABSTRACT

Introducing alternatives material on cement-based material manufacturing is the need for environmental sustainability due to the excessive mining of sand from quarry and river bed. At the same time, industrialization headed to an uncontrollable growth of waste. This fact encourages the researcher to enhance the utilization of recycled waste in construction practice. On one side, it affords a solution for waste management, and on the other hand, it contributes to an eco-friendly construction material that minimizes the environmental impact. This paper aims to investigate the usability of the iron waste obtained from the wrought iron industry, as natural fine aggregates replacement. In particular, it focused on studying the physical characteristic of waste aggregates and the effect of partial replacement of natural sand on mortar strength. Mortar cube specimen made with various levels of replacement (0%, 10%, 20% and 30 %) and also various cement-aggregates volumetric proportion, which are 1:3, 1:4, 1:5, 1:6, and 1:7. All of the measurement parameters are taken consecutively based on ASTM norms. The current work remarks that both waste aggregates and natural aggregates reveal complete fulfillment in the aggregate requirement of ASTM standard. Furthermore, the mortar cube test confirmed that the mortar passes the strength grade for N class and O class, which suitable for the above-grade and non-load bearing application.

Keyword: *mortar, waste, strength.*

I. INTRODUCTION

The extraction of material from the river reaches a number ranging from 10.000 m^3 to 230 million m^3 per year, which managed to a serious problem such as destabilization of riverbank and river bed, also an aquatic environment degradation (Koehnken & Rintoul, 2018). On the other hand, the manufacturing process, including the iron/steel making and electricity generator, produces waste such as slag, foundry sand, coal ash, and cupola sand, which formed in enormous quantities (Takeshi et al., 2018; Lim et al., 2016; Suhendro, 2014). The negative impact of the phenomenon abovementioned could be minimized by expanding the usage of recycled waste as a natural material replacement and reducing the cement content, which brings to lower CO_2 emissions (Glavind & Jepsen, 2002; Srivastra & Singh, 2020).

Figure 1. iron industry waste

Figure 2. Environmental problem due to waste disposal

Numerous studies have reported various successful employment of waste on the eco-friendly mortar. You et al. (2019) pointed out that the use of steel slag and ferronickel slag waste on alkali-activated mortar posses a remarkable result on hydration heat, porosity, and ion chloride diffusion compared to PC mortar. Besides, Lu et al. You et al. (2019) also reveal that the use of blast oxygen furnace slag as fine aggregates had comparable strength and volumetric expansion to ordinary cement mortar. Furthermore, the possibility of complete replacement of natural sand was reported by Mohammadhosseini et al. (2019), which explains that the ceramic waste aggregates posses a satisfy compressive strength and chloride resistance. Moreover, waste material also proved to be used as a binder material, which documented in Liu et al. (2019). The replacement of portland cement at the level of 60 % incorporating high volume waste glass achieved extraordinary strength (99 MPa) while at the same time also reducing the hydration rate, which means a lower hydration heat during the curing process (Liu et al., 2019).

Concerning the presented development of sustainable mortar, the present work aims to study the iron waste characteristic to discover the suitability to be used as cement-based material, replacing the natural sand utilization. Furthermore, to examine the influence of incorporation of the iron waste on the compressive strength and density of mortar, several percentages of sand replacement was introduced. Thus, utilizing iron waste as replacement material would help overcome the iron waste problem.

II. METHODS

Two kinds of fine aggregates involved in the experiments: natural sand obtained from Merapi mountain, and manufactured sand (Fig.1) collected from the disposal area of iron industry waste in Pakis Regency, Central Java (Fig.2). The chunk shaped iron waste being crushed into sand-like particle size. Both aggregates then tested according to ASTM C144 and C33/|C33M to discover the physical properties, including particle grading, density, specific gravity, clay lumps, and water absorption. The result then compared to ASTM requirements to decide whether the aggregates are suitable for mortar producing or not.

The mortar cube specimen produced according to ASTM C109/109M-07 with a length of 50 mm, a width of 50 mm, and a thickness of 50 mm. As a binder material in mortar fabrication, portland cement type II (w/c 0.45) is used several mix designs with various cement-aggregates ratios based on the volumetric proportion, which are 1:3, 1:4, 1:5, 1:6 and 1:7. Different levels of partial replacement are also involved (0 %, 10 %, 20%, and 30 %) to examine the effect of partial replacement of natural sand with waste aggregates on mortar strength and density. Thus, in total, the experiments involving 25 variations of mix design at various cement-aggregates proportion and percentage of sand replacement, which each variation consists of three cube specimens. The produced cube then being cured for 28 days, followed by density test and compressive strength test.

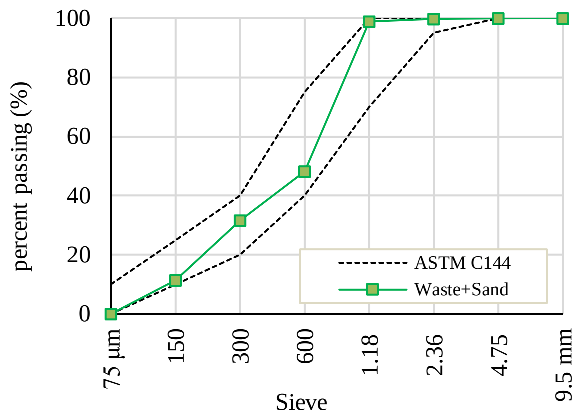

Figure 5. Mixed aggregates grain size distribution

III. RESULT AND DISCUSSION

The aggregates grading is an essential parameter for concrete and mortar since it affects the ductility and elastic modulus because the non-uniform distribution of sand particles created a sparsed structure in the mortar (Haach et al., 2010). Fig.3 shows the grain size distribution curves of the waste aggregates after its crushing process to adjust the particles. At the same time, Fig.4 explained the granulometry of natural sand without any treatment.

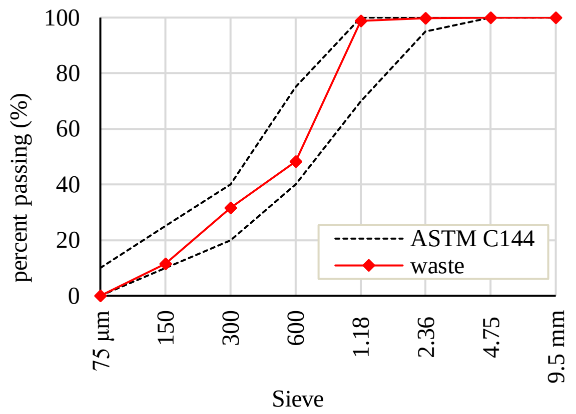

Figure 3. Waste aggregates grain size distribution

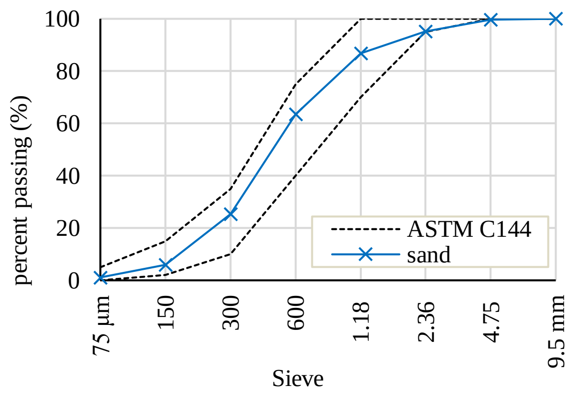

Figure 4. Natural sand grain size distribution

It can be seen that both of the aggregates comply with the grading limit of ASTM, which means that the waste and natural sand ready to be used in mortar manufacturing. Furthermore, because of several levels of sand replacement using waste being introduced, the aggregate mixing carried out by adjusting grain size of the mixed aggregate to fulfill the ASTM provision for manufacturing sand, as displayed in Fig.5.

Table 1. Aggregates physical properties

Parameters	Waste aggregates	Natural sand
Fineness modulus	3.10	3.22
Clay lumps	8.51 %	2.08%
Bulk density (gr/cm^3)	1.158	1.405
Water absorption	13.63 %	6.38%
Bulk specific gravity	1.76	2.47
SSD specific gravity	2	2.63
Moisture content	6.27%	4.65%

The aggregate density along with the grain size also affecting the compactness of the mortar matrix, which means that finer particles can fill the voids, which then might improve the mortar density and resistance (Amaral et al., 2019; Mohammadhosseini et al., 2019). The density of the waste aggregates measured at about 1.158 gr/cm^3, while the natural sand around 1.405 gr/cm^3. Furthermore, the waste and sand have a moisture content of about 6.27% and 4.65 % respectively and judged that the aggregates are dry enough to be used directly in a mixing process. Excessive water content in aggregates increasing the water-cement ratio, which leads to lower strength and resistance (Amaral et al., 2019).

Table 2 and Fig 7 explained the average density of the specimen in each variation. As depicted in Fig

7 and Table 2, the density of the cured mortar reduced 5 to 17 % along with the increase of waste aggregates content, which was expected because of the lower density of waste, compared to natural sand. At the same time, the reduction of cement content also induces a decrease in the mortar density.

Table 2. Compressive strength and density of mortar

Cement-agg. proportion	Average compressive strength [MPa]				Average density [gr/cm^3]			
	0 %	10 %	20 %	30 %	0 %	10 %	20 %	30 %
1:3	7.63	5.72	7.21	7.39	2.00	1.90	1.90	1.87
1:4	5.45	3.01	2.87	2.15	1.93	1.80	1.84	1.75
1:5	4.61	1.06	1.75	1.05	1.96	1.71	1.76	1.77
1:6	2.99	0.74	1.09	1.10	1.99	1.68	1.75	1.71
1:7	2.74	0.19	0.64	0.31	1.96	1.58	1.70	1.66

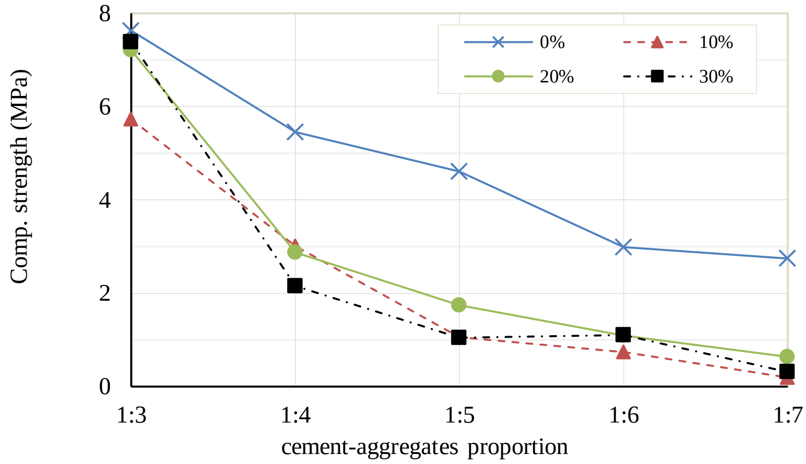

Figure 6. Compressive strength of mortar

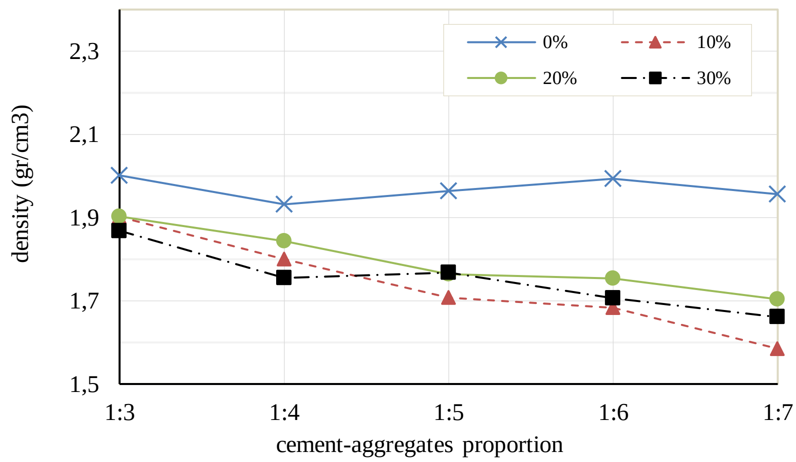

Figure 7. Mortar density test

The recorded compressive strength value explained in Fig 6 and Table 2. At the curing period of 28 days, the reference sample with 0 % waste reveals the highest strength of 7.36 MPa and the lowest about 2.74 MPa, which reached by cement-aggregates proportion 1:3 and 1:7 respectively. It was also observed that partial replacement employing waste also degrades the strength ranging from 25% to 89 % compared to non-waste mortar. Furthermore, the significant strength variability pointed out only in the cement-aggregates proportion that greater than 1:4.

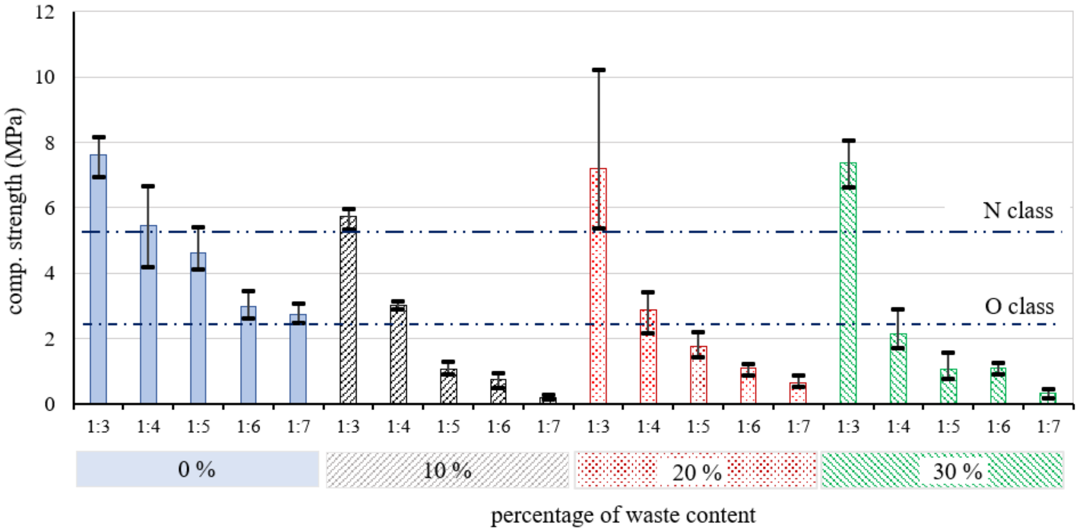

Figure 8. compressive strength classified based on percentage of waste

However, in the 1:3 cement-aggregates ratio, the specimen having a close variability between non-waste mortar and waste aggregate mortar seen from the strength of specimen, which applies 0 %, 20%, and 30% waste. This fact considered caused by the high clay lumps in the waste aggregates (around 8.51 %), as presented in Table 1. The high volume of clay and organic impurities influence the quality of the bond between aggregates and cement paste. Thus, as the addition of waste means that the clay content is risen, followed by the reduction of cement content, the strength is reduced significantly.

ASTM C270-14a has regulated the classification of the mortar used in unit masonry, which divided into four classes (M, S, N, O) based on its compressive strength. Based on the standard aforementioned, the addition of waste material achieved the N class mortar (f'c >5.2 MPa) by use of 1:3 proportion with all replacement percentages (Fig.8). At the same time, the use of 1:4 proportion only satisfied O class mortar (f'c >2.4 MPa). Therefore, the mortar that being proposed suitable for the above-grade masonry work and non-load bearing function.

IV. CONCLUSION

This research carried on an experimental on the physical properties of iron waste aggregates and the strength properties of mortar with a various level of natural sand replacement. According to the result of the conducted experiments, the following concluded:

- The physical characteristic of waste aggregates and natural sand posses a fulfillment of ASTM requirement
- The increase of waste incorporated, affect the strength and density which is lower than non-waste mortar
- The mortar containing up to 30% waste with 1:3 and 1:4 cement-aggregates proportion poses a good compliment of N class and O class mortar, respectively.

V. ACKNOWLEDGEMENTS

Authors wishing to acknowledge Universitas Sarjanawiyata Tamansiswa for the funding support (Penelitian Terapan Unggulan Scheme). The authors would also like to acknowledge Shendi Andika Affaro, Kholif Ramadhan, and Fries Steven Menanga for help on data collection.

VI. REFERENCES

Srivastava, S.K. Singh, Utilization of alternative sand for preparation of sustainable mortar: a review, J. of Cleaner Production, (2020)

ASTM, C144-02 Standard specification for aggregate for masonry mortar, ASTM International, Pensylvania, 2002.

ASTM, C33/C33M Standard Specification for Concrete Aggregates, ASTM International, Pensylvania, 2013.

ASTM, C109/C109M-07 Standard Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens), ASTM International, Pensylvania, 2008.

ASTM, C270-14a Standard Specification for mortar for unit masonry, ASTM International, Pensylvania, 2017

B. Suhendro, Toward green concrete for better sustainable environment, Procedia Engineering, 95 (2014) 305.

G. Liu, M.V.A. Florea, H.J.H. Brouwers. Performance evaluation of sustainable high strength mortars incorporating high volume waste glass as binder. Construction and Building Materials. 202 (2019) 574-588

H. Mohammadhosseini, N.H.A.S. Lim, M.M. Tahir, R. Alyousef, H. Alabduljabbar, M. Samadi, Enhanced performance of green mortar comprising high volume of ceramic waste in aggressive environments. Construction and Building Materials. 212 (2019) 607-617

J.W. Lim, L.H. Chew, T.S.Y. Choong, C. Tezara, M.H. Yazdi, Overview of steel slag application and utilization, MATEC Web of conferences, 74 (2016).

L.F. Amaral, G.C.G. Delaqua, M. Nicolite, M.T. Marvila, A.R.G. de Azevedo, J. Alexandre, C.M.F. Vieira, S.N. Monteiro, Eco-friendly mortars with addition of ornamental stone waste- a mathematical model approach for granulometric optimization, Journal of Cleaner Production, (2019)

L. Koehnken, M. Rintoul, Impacts of sand mining on ecosystem structure, Process and Biodiversity in Rivers, WWF, Switzerland, 2018.

M. Takeshi, T. Hiroyuki, W. Kenji, Iron and steel slag products and new effective utilization technologies, JFE Technical Reports, 23 (2018) 62-68.

M. Glavind, M.T. Jepsen, Evaluation ofgreen concrete. XVIII Symposium on Nordic Concrete Research, (2002)

N. You, B. Li, R. Cao, J. Shi, C. Chen, Y, Zhang, The influence of steel slag and ferronickel slag on the properties of alkali-activated slag mortar, Construction and Building Materials, 227 (2019) 116614

T.H. Lu, Y.L. Chen, P.H. Shih, J.E. Chang, Use of basic oxygen furnace slag fines in the production of cementitious mortars and the effect on mortar expansion. Construction and Building Materials. 167 (2018) 768-774

V.G. Haach, G. Vasconcelos, P.B. Lourenco, Influence of aggregates grading and wate/cement ratio in workability and hardened properties of mortars. Construction and Building Materials, 25 (2010) 2980-2987