EFFECT OF STEEL SLAG AND STEEL SLUDGE ON CONCRETE PROPERTIES

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Specially dedicated to my mother, father and my family member
I really miss all of you.

Roslan bin Sharif & Jamilah bt Nekmat

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ABSTRACT

The wastes generated from steel industries are known to be as sludge and slag. The problem with some of these by-products is they contain large amount of heavy metals that can be leached out to the environment and cause pollution. Several studies have been conducted on steel slag as a replacement for cement in concrete but it is still not sufficient and well established. However, there is no significant research carried out using steel sludge in concrete. This study represents the results of electric arc furnace steel slag and steel sludge for replacing cement materials. Both materials were investigated for their pozzolanic properties, strength, and durability. Initially, the steel slag and steel sludge were screened for pozzolanic properties using pozzolanic activity test based on ASTM C618 and thermogravity method. Then they were incorporated in concrete mixes by replacing cement from 5% to 20%. The specimens were tested at its fresh and hardened state. The fresh concrete was also tested for slump and concrete grade 25 for its strength and durability at 7, 28 and 90 days. For durability performance, the specimens were tested for their initial surface absorption, water absorption and leaching test. The morphology testing of the concrete was also carried out. It was found that steel slag and steel sludge showed positive pozzolanic activity based on pozzolanic activity test. In addition, it was found that the compressive strength for concrete containing steel slag and steel sludge increased up to 10% replacement and started to decrease in strength beyond the replacement level. It clearly shows that 10% replacement of steel slag and steel sludge is the optimal percentage that is required for the replacement. In case of durability, both replacement of cement by steel slag and steel sludge can be categorised as low permeability. Denser structure, less pores and rougher surface were seen in the morphology of 10% steel slag. The heavy metals are found to be effectively solidified and stabilized in the cement-based matrix. In conclusion, steel slag and steel sludge showed good potential to be used in the replacement of cement materials. Moreover, the use of steel slag and steel sludge in concrete can certainly help in preserving the environment.

ABSTRAK

Sisa yang biasa dihasilkan daripada industri keluli ialah sisa enapcemar dan sanga. Masalahnya ialah sesetengah hasil sampingan ini mungkin mengandungi kuantiti logam berat yang boleh terlarut lesap ke alam sekitar dan mengakibatkan pencemaran. Beberapa kajian terhadap sanga keluli sebagai bahan gantian simen di dalam konkrit telah dijalankan sebelum ini, tetapi ianya masih tidak mencukupi dan mantap. Walau bagaimanapun, tidak ada kajian telah dilakukan dengan menggunakan enapcemar keluli dalam konkrit. Kajian ini membentangkan keputusan sanga relau arka elektrik keluli dan enapcemar keluli sebagai bahan gantian simen. Kedua-dua bahan ini disiasat potensi sifat- sifat pozzolanik, kekuatan mekanikal dan ketahananlasakan. Pada mulanya sanga keluli dan enapcemar keluli telah diuji sifat pozzolanik melalui ujian aktiviti pozzolanik, ujian spesifikasi pozzolan berdasarkan ASTM C618 dan ujian 'Thermogravity'. Sanga keluli dan keluli enapcemar digabungkan dalam campuran konkrit dengan menggantikan simen dari 0% sehingga 20 %. Spesimen-spesimen konkrit diuji pada keadaan segar (baru) dan keras. Kebolehkerjaan konkrit diuji pada konkrit segar manakala ujian kekuatan dan ketahanan ujian pada konkrit gred 25 pada 7, 28 dan 90 hari. Bagi prestasi ketahananlasakan konkrit, spesimen diuji melalui ujian penyerapan awal permukaan (ISAT), ujian penyerapan air dan ujian larut lesap. Ujian morfologi juga dijalankan ke atas konkrit. Sanga keluli dan enapcemar keluli menunjukkan sifat pozzolanik positif daripada ujian aktiviti pozzolanik. Di samping itu, didapati bahawa kekuatan mampatan bagi konkrit yang mengandungi sanga keluli dan enapcemar keluli meningkat pada penggantian 10% dan kekuatan mula berkurangan apabila lebih dari tahap penggantian itu. Ia menunjukkan bahawa penggantian 10% daripada sanga keluli dan keluli enapcemar adalah peratusan gentian yang optimum. Bagi kes ketahananlasakan pula, kedua-dua konkrit penggantian oleh sanga keluli dan enapcemar keluli boleh dikategorikan sebagai ketelapan rendah. Struktur padat, kurang liang dan permukaan kasar dapat dilihat dalam morfologi 10% keluli sanga. Logam berat telah berkesan dikukuh dan distabilkan dalam matriks simen. Kesimpulannya, sanga keluli dan keluli enapcemar menunjukkan potensi yang baik untuk digunakan sebagai bahan pengganti simen. Di samping itu, penggunaan sanga keluli dan enapcemar keluli dalam konkrit boleh membantu dalam memelihara alam sekitar.

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LIST OF ABBREVIATION

EAFS	-	Electric arc Furnace Steel Slag
GGBS	-	Ground Granulated Blastfurnace Steel Slag
POFA	-	Palm Oil Fuel Ash
FA	-	Fly Ash
SF	-	Silica Fume
OPC	-	Ordinary Portland Cement
CO_2	-	Carbon Dioxide
FESEM	-	Field Emission Scanning Electron Microscope
C2S	-	Dicalcium Silicate
C3S	-	Tricalcium Silicate
C3A	-	Tricalcium Aluminate
C4AF	-	Tetracalcium Aluminoferrite
MgO	-	Magnesium Oxide
C-S-H	-	Calcium Silicate Hydrates
CaOH2 / CH	-	Calcium Hydroxide
TGA	-	Thermogravimetric Analysis
DTA	-	Differential Thermal Analysis
w/b	-	water/binder
w/c	-	water/cement
w/cm	-	water/cementitious materials
UTM	-	Universiti Teknologi Malaysia
CRM	-	cementitious replacement material
ASTM	-	American Standard Testing Method
BS	-	British Standard
ISAT	-	Initial Surface Absorption Test

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Sustainable development in the cement and concrete industries now becoming a global focus and it is not an easy goal to achieve. Understanding concept and how to design for sustainable development is important in achieving a sustainable development. Swamy (2000) believes that to achieve sustainable development, some important factors should be considered in designing, including site waste minimization, recycle waste, reduce waste, and least damage to environment. These factors are in regard to waste management.

Waste management attempts to provide an environment friendly process through decreasing the quantity of waste materials and by removal of process in landfill. If waste materials are managed appropriately (e.g., reducing the cost of waste disposal, conserving raw materials, and utilizing the materials efficiently), there will be numerous advantages both environmentally and economically. Qasrawi et al., (2009) points out that the quantity of waste that is produced every day leads to harmful problems for both environment and factories. The disposal of waste materials requires a high expense that has to be paid by factories; furthermore, the disposal process has negative effects on the environment.

Batayneh et al., (2007) warns that because of the advancement of technology in the current modern world and changes to the people's lifestyle, the globe witnesses an augment in the type and amount of waste materials, which leads to a crisis in waste disposal as well as big problems in the environment. Large amount of waste materials cannot be removed completely. Nevertheless, we can reduce the negative environmental impacts by more sustainable utilization of the waste materials. For the disposal or reduction of waste substances, a suggestion is the use of them as primary materials in Portland cement concrete (OPC). This will saves natural resources and dumping spaces, and helps to maintain a clean environment.

Concrete being the most widely used construction material, has seen its consumption rise with the growth in population and development. Concrete is affordable and reliable material that is applied throughout the infrastructure of any kinds of construction development. The replacement of OPC by the active nano-powders or the supplementary cementing materials like silica fume (SF), ground granulated blast furnace slag (GGBS), fly ash (FA), or rice husk ash (RHA) plays an important role in the eco-efficiency and global economy (Susan et al., 2010).

Das et al. (2007) stated that advanced of technology has lead to rapid development in steel producing industry and lead to the increases of the waste materials from steel producing process. Significant quantities of sludge and slag are generated as waste material or byproduct every day from steel industries. In this study, there are two by-products from steel industry to be investigated by assessing their potential to be use in concrete. The materials are steel slag and steel sludge.

1.2 Background of the study

Climate change and the impact of greenhouse gas emissions on our environment have caused many researchers to focus on CO_2 emissions as the most critical environmental impact. According to Obla (2009), the production of 1 ton of cement released about 0.9 tons of CO_2 emissions. This problems lead to the efforts on reducing greenhouse gas emissions. This contributes to the effort through the use of lower amounts of cement and higher amount of supplementary cementitious material in concrete such as fly ash and slag and other established supplementary. So, much intention is paid to using supplementary cementitious material in concrete.

Despite many desirable properties known for the Conventional Portland cement concrete, this suffers several problems that have limited its utilization, e.g., poor durability, low tensile strength, susceptibility to acid and sulphate attacks. In case of some applications, these above-mentioned problems have been solved. Each of the applications and preceding treatments attempt to improve quality of concrete and provide the solution to a particular problem. Some problems can be solved by incorporation of waste material as a cement replacement in concrete. This application will help to improve the strength and the durability of concrete.

New by-product and waste material are being generated by various industries especially in steel industry. Das et al. (2007) report that in steel production industry; for producing one ton of steel, two to four tons of wastes are generated in the form of steel sludge and steel slag. The problem is, the steel slag and steel sludge may contain an amount of heavy metals and if these materials not manage properly, it will contribute to environmental problems when disposed to the landfill.

Steel slag is normally a by-product of the extraction and refining process of different metals. In a given metal production process, the slag is produced in three stages: blast furnace slag, electric arc furnace slag and ladle slag (Muhmood et al., 2009). Nowadays, the electric arc furnace technology is widely used at present, permitting the steel manufacturing from metal scrap (Frías Rojas & Sánchez de Rojas, 2004). Few researchers study on using this material as cement replacement and this lead to conducting this research (Muhmood et al., 2009). Several studies have been conducted on utilization of steel slag as aggregate for concrete (see Chunlin et al., 2011; Abu-Eishah et al., 2012; Manso et al., 2006; Motz & Geiseler, 2001; Maslehuddin et al., 2003; Qasrawi et al., 2009; Pellegrino & Gaddo, 2009)

Another material produced from steel industry is the steel sludge. Steel sludge was obtained from the steel wire production. During the production of steel wire, the steel are draw into a desired shape and size. The sludge from this process is used in this study. At present, there is no research perform on the use of steel sludge in concrete. Evaluation of potential of steel sludge is important due to its high heavy metal content. The present research evaluates the suitability of the steel sludge and steel slag as the cement replacement in normal concrete mixes.

1.3 Problem Statement

Due to the generation of high amount of waste materials or by-products, the potential of these wastes to be used in concrete was evaluated. The use of these waste materials will certainly reduce the cement production cost including the natural resources such as aggregates. Steel industry generates a lot of slag and sludge as by-product or waste material. In some of these by-products, there is presence of sufficient amount of heavy metals that can be released to the earth which can cause environmental related problems.

A proper management of this waste material or by-product needs to be carried out in order to reduce the impact on environment. The potential use of steel slag and steel sludge for replacing cement was carried out. Besides, the use of waste material will facilitate in overcoming few of the concrete problems. The properties and durability of concrete can be improved using a cement replacement material in concrete.

Many studies have shown the success of utilizing steel slag as aggregate in concrete and as road based material for road construction. However, studies on steel slag as cement replacement in concrete is still not sufficient and well established. Previous studies have shown the evaluation of potential use of steel slag in terms of strength and durability performance. But, some of the findings have shown no correlation between those studies. It shows that there are some properties which will affect the performance. Hence, further study is required to understand the properties of steel slag and its performance in concrete. Besides, there is no significant research being carried out so far in evaluating the performance of steel sludge to be used in concrete.

Hence, clear understanding about the properties and the effects of steel slag and steel sludge when mixed into the concrete needs to be investigated. The properties to be investigated include the materials characteristic, workability, strength development and durability of the concrete.

1.4 Aim and Objectives of Study

The aim of this research is to evaluate the potential use of steel slag and steel sludge to be used in concrete. The specific objectives are as follows:

i. To characterize steel slag and steel sludge by evaluating the pozzolanic properties of steel slag and steel sludge

ii. To determine the optimum quantity of steel slag and steel sludge to be added into concrete to attain reasonable strength.

iii. To investigate the physical, mechanical and chemical performances of concrete containing steel slag and steel sludge.

1.5 Scope of the Study

The study involves the mixing of concrete with a several percentage of waste material into the concrete to meet the design strength of concrete. The testing covered the properties of concrete at fresh and hardened of normal grade concrete 25. The testing of concrete involves workability test, strength test and durability test. The samples were cured at 7^{th}, 28^{th} and 90^{th} days. The test was done in concrete laboratory at Faculty of Civil Engineering, UTM.

1.6 Organization of Thesis

This thesis consists of six chapters. **Chapter One** presents the background of the study, aim and objectives as well as scope of study. Besides, thesis layout is included in this chapter.

Chapter Two carries the literature review and represents the findings from it. The literature review is focused on the previous work done by other researchers which covers the materials used in the composite material, hydration of cement, cement replacement materials, applications of steel slag and steel sludge, tests in this study and brief introduction. At the end of the chapter, the summary of the literature review is concluded.

Chapter Three illustrates the methodology, materials and experimental approached used in this study. The collection of materials and laboratory experiments were carried in accordance to the procedures outlined by various standards like ASTM and BS. Guidelines by established authors were adopted wherever the procedures regarding certain tests are not found in the standards.

Chapter Four elaborates on the results obtained from the materials characterization and the pozzolanic activity. The results comprise of steel slag and steel sludge properties, and the evaluation of steel slag and steel sludge as a pozzolanic materials.

Chapter Five discusses the results optimization of mix, effect of steel slag and steel sludge on the strength, durability, morphology and the leaching of heavy metals. At the end of the chapter, substantial conclusions are drawn.

Chapter Six concludes the results of the study and discussions are made on the achievement of the objectives of the study. It also outlines the recommendations for the future research.

REFERENCES

Abdul Majid Z. (2004). *Stabilization/solidification of Toxic and Hazardous Waste :Engineering and Chemical Considerations*. Ph.D. Thesis. Universiti Malaya, Kuala Lumpur.

Abu-Eishah, S. I., El-Dieb, A. S., & Bedir, M. S. (2012). Performance of Concrete Mixtures Made with Electric Arc Furnace (EAF) Steel Slag Aggregate Produced in the Arabian Gulf region. *Construction and Building Materials*, *34*, 249–256.

American Standards of Testing and Materials (2012). *ASTM C618-12 : Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete.* United States: American Standards of Testing and Materials.

Andrade, P. M., Vieira, C. M. F., Monteiro, S. N., & Vernilli Jr., F. (2006). Recycling of Steel Sludge into Red Ceramic. *Materials Science Forum, 530-531*, 544–549.

Anif, B. (2009). *Sifat-Sifat Konkrit Dengan Jermang Relau Arka Elektrik*. Doctor of Philosophy, Universiti Teknologi Malysia, Skudai.

Bagheri, A.R., Zanganeh, H. & Moalemi, M.M., 2012. Mechanical and Durability Properties of Ternary Concretes Containing Silica Fume and Low Reactivity Blast Furnace Slag. *Cement and Concrete Composites*, 34(5), pp.663–670.

Batayneh, M., Marie, I., & Asi, I. (2007). Use of Selected Waste Materials in Concrete Mixes. *Waste Management (New York, N.Y.)*, *27*(12), 1870–6.

Borrachero, M. V, Monzo, J., Amahjour, F., & Paya, J. (2001). Enhanced Conductivity Measurement Techniques for Evaluation Of Fly Ash Pozzolanic Activity, *31*, 41-49.

British Standard Institution (1983). *BS1881: Part 102: Method for determination of slump*. London: British Standard Institution.

British Standard Institution (1983). *BS 1881-121: Method For Determination of Static Modulus of Elasticity In Compression*. London: British Standard.

British Standard Institution (1996). BS 1881-208: *Recommendations for the Determination of the Initial Surface Absorption of Concrete*. London: British Standard Institution Institution.

British Standard Institution (2000). *BS EN 12390 Part 4: Compressive Strength - Specification for Testing Machines.* London: British Standard Institution.

British Standard Institution (2000). *BS EN 12390 Part 5: Flexural Strength of Test Specimens*. London: British Standard Institution.

British Standard Institution (2000). *BS EN 12390 Part 6: Tensile Splitting Strength of Test Specimens*. London: British Standard Institution.

British Standard Institution (2011). *BS 1881: Part 122: Method for Determination of Water Absorption.* London: British Standard Institution.

Chunlin, L., Kunpeng, Z., & Depeng, C. (2011). Possibility of Concrete Prepared with Steel Slag as Fine and Coarse Aggregates: A Preliminary Study. *Procedia Engineering*, *24*, 412–416.

Çolak, A. (2003). Characteristics of Pastes from a Portland cement Containing Different Amounts of Natural Pozzolan. *Cement and Concrete Research*.

Darquennes, A., Espion, B., & Staquet, S. (2013). How to Assess the Hydration of Slag Cement Concretes? *Construction and Building Materials*, *40*, 1012–1020.

Das, B., Prakash, S., Reddy, P. S. R., & Misra, V. N. (2007). An Overview of Utilization of Slag and Sludge from Steel Industries. *Resources, Conservation and Recycling*, *50*(1), 40–57.

Eglinton M. S. (1987). *Concrete and Its Chemical Behaviour*. London: Thomas Telford Ltd.

Frías Rojas, M., & Sánchez de Rojas, M. I. (2004). Chemical Assessment of the Electric Arc Furnace Slag as Construction Material: Expansive Compounds. *Cement and Concrete Research*, *34*(10), 1881–1888.

Karim, R., Zain, M., Jamil, M., & Ismail, N. (2011). Strength of Concrete as Influenced by Palm Oil Fuel Ash. *Australian Journal of Basic and Applied Sciences*, *5*(5), 990–997.

Kroehong, W., Sinsiri, T., Jaturapitakkul, C., & Chindaprasirt, P. (2011). Effect of Palm Oil Fuel Ash Fineness on the Microstructure of Blended Cement Paste. *Construction and Building Materials*, *25*(11), 4095–4104.

Li, X. M., Wang, S. J., Zhao, J. X., Cui, Y. R., & Hou, S. B. (2011). A Review on the Treatments and Minimization Techniques of Stainless Steel Pickling Sludge. *Advanced Materials Research*, *194-196*, 2072–2076.

Liu, T., & Chern, J. (2008). Sustainable Concrete Technology for the 21th Century. *The 3rd ACF International Conference, ACF/VCA*.

Luxán, M. P., Sotolongo, R., Dorrego, F., & Herrero, E. (2000). Characteristics of the Slags Produced in the Fusion of Scrap Steel by Electric Arc Furnace. *Cement and Concrete Research*, *30*(4), 517–519.

Malliou, O., Katsioti, M., Georgiadis, a., & Katsiri, a. (2007). Properties of Stabilized/Solidified Admixtures of Cement and Sewage Sludge. *Cement and Concrete Composites*, *29*(1), 55–61.

Manso, J. M., Gonzalez, J. J., & Polanco, J. A. (2004). Electric Arc Furnace Slag in Concrete, (December), 639–645.

Manso, J. M., Polanco, J. a., Losañez, M., & González, J. J. (2006). Durability of Concrete Made with EAF Slag As Aggregate. *Cement and Concrete Composites*, *28*(6), 528–534.

Mary, V. (2002). *Performance Characteristics of Electric Arc Furnace Slag Concrete*. Master of Engineering , Universiti Teknologi Malaysia, Skudai.

Maslehuddin, M., Sharif, A. M., Shameem, M., Ibrahim, M., & Barry, M. . (2003). Comparison of Properties of Steel Slag and Crushed Limestone Aggregate Concretes. *Construction and Building Materials*, *17*(2), 105–112.

Massazza, F., 1998. Pozzolana and Pozzolanic Cements. *Lea's Chemistry of Cement and Concrete*, 4th edition

Megat Azmi, M. J., Ramadhansyah, P. J., & Abu Bakar, B. H. (2011). Effect of Rice Husk Ash Fineness on the Chemical and Physical Properties of Concrete. *Magazine of Concrete Research*, *63*(5), 313–320.

Montgomery, D., Sollars, C., & Perry, R. (1988). Cement-Based Solidification for the Safe Disposal of Heavy Metal Contaminated Sewage Sludge. *Waste Management & Research*.

Mostafa, N. Y., Mohsen, Q., El-Hemaly, S. a. S., El-Korashy, S. a., & Brown, P. W. (2010). High Replacements of Reactive Pozzolan in Blended Cements: Microstructure and Mechanical Properties. *Cement and Concrete Composites*, *32*(5), 386–391.

Motz, H., & Geiseler, J. (2001). Products of Steel Slags an Opportunity to Save Natural Resources. *Waste Management (New York, N.Y.)*, *21*(3), 285–93.

Muhmood, L., Vitta, S., & Venkateswaran, D. (2009). Cementitious and Pozzolanic Behavior of Electric Arc Furnace Steel Slags. *Cement and Concrete Research*, *39*(2), 102–109.

Neville, A. (1995). *Properties of concrete*. 2nd Edition. Wiley (New York).

Obla, K. H. (2009). What is Green Concrete ?, The Indian Concrete Journal (April), 26–28.

Pane, I., & Hansen, W. (2005). Investigation of Blended Cement Hydration by Isothermal Calorimetry and Thermal Analysis. *Cement and Concrete Research*, *35*(6), 1155–1164.

Pasetto, M., & Baldo, N. (2011). Mix design and Performance Analysis of Asphalt Concretes with Electric Arc Furnace Slag. *Construction and Building Materials*, *25*(8), 3458–3468.

Pekmezci, B. Y., & Akyüz, S. (2004). Optimum Usage of a Natural Pozzolan for the Maximum Compressive Strength of concrete. *Cement and Concrete Research*, *34*(12), 2175–2179.

Pellegrino, C., Cavagnis, P., Faleschini, F., & Brunelli, K. (2013). Properties of Concretes with Black/Oxidizing Electric Arc Furnace Slag Aggregate. *Cement and Concrete Composites*, *37*, 232–240.

Pellegrino, C., & Gaddo, V. (2009). Mechanical and Durability Characteristics of Cconcrete Ccontaining EAF Slag as Aggregate. *Cement and Concrete Composites*, *31*(9), 663–671.

Pourkhorshidi, A. R., Najimi, M., Parhizkar, T., Jafarpour, F., & Hillemeier, B. (2010). Applicability of the Standard Specifications of ASTM C618 for Eevaluation of Natural Pozzolans. *Cement and Concrete Composites*, *32*(10), 794–800.

Qasrawi, H., Shalabi, F., & Asi, I. (2009). Use of low CaO Unprocessed Seel Slag in Soncrete as Fine Aggregate. *Construction and Building Materials*, *23*(2), 1118–1125.

Rukzon, S., Chindaprasirt, P., & Mahachai, R. (2009). Effect of Grinding on Chemical and Physical Properties of Rice Husk Ash. *International Journal of Minerals, Metallurgy and Materials*, *16*(2), 242–247.

Scrivener, K. L., & Nonat, A. (2011). Hydration of Cementitious Materials, Present and Future. *Cement and Concrete Research*, *41*(7), 651–665.

Shafiq, N., & Nuruddin, M. (2011). Degree of Hydration of OPC and OPC/Fly Ash Paste Samples Conditioned at Different Relative Humidity. *International Journal of Sustainable*

Sinthaworn, S., & Nimityongskul, P. (2011). Effects of Temperature and Alkaline Solution on Electrical Conductivity Measurements of Pozzolanic Activity. *Cement and Concrete Composites*, *33*(5), 622–627.

Stark, J. (2011). Recent Advances in the Field of Cement Hydration and Microstructure Analysis. *Cement and Concrete Research*, *41*(7), 666–678.

Swamy, R. N. (2000). Designing Concrete and Concrete Structures for Sustainable Development Designing. In *Two-Day CANMET/ACI International Symposium on Concrete Technology for Sustainable Development*.

Uzal, B., Turanlı, L., Yücel, H., Göncüoğlu, M. C., & Çulfaz, a. (2010). Pozzolanic Activity of Clinoptilolite: A comparative Study with Silica Fume, Fly Ash and a Non-Zeolitic Natural Pozzolan. *Cement and Concrete Research*, *40*(3), 398–404.

Vieira, C. M. F., Andrade, P. M., Maciel, G. S., Vernilli, F., & Monteiro, S. N. (2006). Incorporation of fine Steel Sludge Waste into Red Ceramic. *Materials Science and Engineering: A*, *427*(1-2), 142–147.

Weitzman, L. E. O. (1990). Factor for Selecting Appropriate Solidification/ Stabilization Methods, *Journal of Hazardous Materials*, *24*, 157–168.

Wu, S., Xue, Y., Ye, Q., & Chen, Y. (2007). Utilization of Steel Slag as Aggregates for Stone Mastic Asphalt (SMA) Mixtures. *Building and Environment*. 42(7), 2580–2585

Yildirim, I. Z., & Prezzi, M. (2011). Chemical, Mineralogical, and Morphological Properties of Steel Slag. *Advances in Civil Engineering*, *2011*, 1–13.

Yu, Q., Sawayama, K., & Sugita, S. (1999). The Reaction Between Rice Husk Ash and $Ca(OH)_2$ Solution and the Nature of its Product. *Cement and Concrete. 29(1),* 37-43

Zhang, T., Gao, P., Gao, P., Wei, J., & Yu, Q. (2013). Effectiveness of Novel and Traditional Methods to Incorporate Industrial Wastes in Cementitious Materials—An Overview. *Resources, Conservation and Recycling*, *74*, 134–143.