Effect of Used Engine Oil to High Strength Microwave Incinerated Rice Husk Ash (MIRHA) Concrete

by

Fatin Liana Bt. Zul Hisham

Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Civil Engineering)

JANUARY 2008

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan
Supervisor: AP Ir. Dr. Hj. Muhd. Fadhil Nuruddin

CERTIFICATION OF APPROVAL

Effect of Used Engine Oil to High Strength Microwave Incinerated Rice Husk Ash (MIRHA) Concrete

By

Fatin Liana Bt. Zul Hisham

A project dissertation submitted to the
Civil Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(CIVIL ENGINEERING)

Approved by,

(Assoc. Prof. Ir. Dr. Hj. Muhd Fadhil Nurruddin)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

January 2008

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

FATIN LIANA BT ZUL HISHAM

ABSTRACT

Waste utilization has been a common step taken is most country throughout the world. Other than it could help minimize the depletion of natural resource, waste has no economical value. This research discusses about the possibility of incorporating two kinds of industrial waste; namely used engine oil and rice husk ash in concrete manufacturing. A study was carried out to evaluate the effect of used engine oil to concrete containing rice husk ash on both fresh and hardened concrete properties. Three types of mixes with three different water-binder ratios were cast. Concrete mix with 10% rice husk ash was taken as the control, while the addition of used engine oil in the concrete mix containing 10% of rice husk ash was fixed at 3% and 4% of used engine oil. The results of slump, compressive strength, split tensile strength, and porosity of the concrete were compared to the control mix in order to evaluate the effect of used engine oil to concrete containing rice husk ash. The slump values were not obvious due to the low water-binder ratio used, however, the additional of used engine oil helped in refining the strength development of the concrete. The compressive strength has shown 20% increment, while split tensile strength has proven to rise about 1.6 times greater than the control mix. The porosity also has shown about a 10% reduction lower than the concrete containing only rice husk ash. In conclusion, this study has able to demonstrate the positive effect of used engine oil to concrete hardened properties in enhancing concrete properties.

ACKNOWLEDGEMENT

First and foremost, praised be to Allah, the Most Merciful and the Most Beneficent, who grants the author good health in completing her research within the given time. The author would like to take the opportunity to express her sincere thanks to her supervisor Associate Professor, Ir. Dr. Muhd Fadhil Nuruddin, for his excellent guidance and support throughout the duration of the study. It is a great honor to work and learn under his supervision. The author would also like to thank Associate Professor, Dr. Nasir Shafiq for his encouragement and advice. The author would also like to thank her parents, Mr. Zul Hisham and Ms. Siti Khalijah for their constant love and support. Special thanks are extended to the following people and institutions for their help in conducting this research: Mr. Johan Ariff Bin Mohamed, Mr. Meor Asniwan Meor Ghazali, and Mr. Mohd Idris Bin Mokhtar, Lab Technologist UTP Concrete Laboratory, for their technical advice and materials procurement.

Finally, the author would like to express his deepest gratitude to all parties who have supported her throughout the study and to Universiti Teknologi PETRONAS for providing her appropriate facilities and financial support.

TABLE OF CONTENTS

CHAPTER 1: INTRODUCTION

CHAPTER 2: LITERATURE REVIEW/THEORY

CHAPTER 3: METHODOLOGY

CHAPTER 4: RESULTS AND DISCUSSION

CHAPTER 5: CONCLUSION

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1
INTRODUCTION

1.0 BACKGROUND OF STUDY

High strength concrete (HSC) is mostly preferred to be used in multistory building construction as it reduces the cross-sectional area of the structural element. The potential advantages of HSC extend beyond strength to include improvements in durability and service life of concrete structures. The primary reasons for selecting HSC are to produce a more economical product, provide a feasible technical solution, or a combination of both. However, due to high material (cement) consumption, the cost of HSC is very high. The escalation of cost for building materials as well as the rising environmental concerns due the extensive exploitation of natural resources urges the search for alternative technological options for replacing cement in concrete industries.

Processed and unprocessed wastes or industrial by-products have been recognized widely to be used as raw materials in cement and concrete industry. Some of those wastes include recycled aggregates concrete, which has been mostly used in road construction and industrial by-products such as fly ash, rice husk ash, etc. has been known widely to partially replace cement in concrete manufacturing [6]. From economical perspective, the cost of disposing those wastes i.e. transportation to disposal site, proper treatment of waste plus the strict environmental law can be cut off. Furthermore, improper disposal of waste might bring harmful threats to our environment. However the success of those wastes in concrete is merely depending on the desired end product.

Almost half of the world population is savoring rice as their main food source. The current world production of rice paddy is around 500 million tons and hence 100 millions tons of rice husks are produced [4]. Plus, the world engine oil users which include machineries other than automotives are keeping on growing frenziedly. In 2004, 37.4 million tons of lubricants were consumed worldwide (53% automotive lubricants, 32% industrial lubricants, including related specialties, 5% marine oils, and 10% process oils) [1] .

Numerous researches have been done on rice husk compatibility in partially replacing cement. It was reported that rice husk ash generates pozzolanic reaction; which when combined with calcium hydroxide at room temperature; it will exhibit the cementatious properties – the similar reaction of Portland Cement (PC) when combined with water. An ash with high pozzolanic activity could be obtain by holding the silica in a non-crystalline state and in highly microporous structure [17, 22].A well-known technique that could generate such ash is control burning. Generally, the microwave incinerated rice husk ash (MIRHA) is ashes produced from control combustion of rice husks in a microwave incinerator. Therefore, the ashes produced would have almost equivalent amount of silica as compared to other control burning method, which is much higher (silica) than open burning of rice husks [4].

Recently, there have been number of research done on used engine oil (UEO) effect to concrete properties. Most of the research is done in conjunction with the incident in the early days, where the leakage of oil into the cement factory in older grinding units has been reported to result in concrete with greater resistance to freezing and thawing [5]. Addition of UEO are said to give the superplasticizer effect on concrete [6].

Nevertheless there has been no research so far which combines both wastes together in producing concrete. For that reason, the research assumption of this project is based on the previous studies which being done on the effect of each those waste in concrete properties. Generally, MIRHA and UEO has proven to assist in concrete fresh and hardens properties respectively, thus, for this research, the combination of both (UEO and MIRHA) was assumed to improve the workability and durability of HSC.

1.1 PROBLEM STATEMENT

The cement productions nowadays are facing a lot of challenges including the energy and resource conservation causing the production cost to rise. Approximately one ton of carbon dioxide (CO_2) and other greenhouse gases (GHGs) are released into the atmosphere from the production of one ton of Portland cement [9]. From the environmental concern and the need in protecting our natural resources, many building sectors are now have been attracted to mineral additives as the substitute of cement.

The study of this paper was carried out in the intention of indirectly provide an alternative to the concrete industry for mineral additives. Environmental benefits will be the driving factor, as the use of mineral additives provides a beneficial application for waste materials as well as reducing the energy and GHGs emissions to produce cement. Mineral additives in this context study are referred to the agricultural or industrial by-products in which have been established their benefit in concrete industry i.e. MIRHA and UEO in enhancing the strength and durability of concrete.

Rice husk and used engine oil is basically an agricultural as well as industrial waste product (used engine oil here is specifically referring to the used engine oil for motor-vehicle). However, those by-products cannot be dumped easily to the surroundings. Both materials are considered as pollutants to the environment. Therefore, proper treatment due to the strict environmental law is required before disposing off the waste. This treatment is usually will be very costly to some industries.

Rice husk has posed a major problem of disposal to the rice milling industry in Malaysia and elsewhere in the world. By open burning of the husk, hazardous gas such as CO_2, CH_4 and NO_2 will be emitted; those gases will contribute to haze and also air pollution which lead to health problems. In addition, rice husk possesses rough and abrasive surfaces that are highly resistant to natural degradation [14].

As we all aware of, used engine oil (UEO) is a non biodegradable product. Globally, motor vehicles use one third of the world's oil [1]. Improper disposal of used engine oil will commit terrible impact to the marine and human life. It is estimated that less than 45% of UEO is being collected worldwide while the remaining 55% is thrown by the end user to the environment [6, 7].

This research study was aimed to investigate the effectiveness of used engine oil in order to enhance the properties of MIRHA high strength concrete.

1.2 OBJECTIVES OF PROJECT

The objectives of this project are as follows:

- To produce high strength concrete using MIRHA and used engine oil
- To determine the effect of used engine oil in fresh property of high strength concrete containing MIRHA
- To establish the effect of used engine oil in hardened properties of high strength concrete containing MIRHA

1.3 SCOPE OF WORK

Initially, this project covers the production of MIRHA, by combustion of rice husks in a microwave incinerator, followed by grinding the ashes in a ball mill. In order to evaluate the effect of UEO on MIRHA high strength concrete, in both fresh and hardened properties, the amount of UEO is limited to 3% and 4% of cement weight on alternate concrete mix proportion, while total MIRHA in each mix is equivalent throughout; 10% of the cement amount.

Slump test are carried out during the fresh state of concrete. Destructive test are conducted on hardened properties of concrete i.e. compressive strength, split tensile strength and total porosity.

Nine different types of concrete mix are prepared with three different water-binder ratio (w/b) of 0.40, 0.37 and 0.34 of cement weight. 100 x 100 x 100mm concrete cubes were produced to observe the compressive strength at 3, 7 and 28-days. To obtain more information about the development of strength of concretes, splitting tensile test and porosity on cylinder of 100 x 200mm and 50 x 40mm, were analyzed respectively at the curing age of 28-days.

The total of 81 cubes, 27 cylinders (100 x 200mm) and 27 smaller cylinders (50 x 40mm) are prepared for throughout this research.

CHAPTER 2

LITERATURE REVIEW

2.0 CONCRETE AND ENVIRONMENT

Concrete has been widely selected as a building material due to its durability and strength. The uses of concrete are more economical compare to wood and steel [8]. Concrete is made by mixing cement, water, coarse and fine aggregates plus admixtures (if required). The aim is to mix these materials in measured amount to make concrete that is easy to transport, place, compact and finish and which will set and harden resulting a strong and durable product.

Properties of hardened concrete are affected by the amount of each ingredient (i.e. cement, water and aggregates) which influence by the desired end products. Cement is an essential material in concrete manufacturing. Cement will act as a binder to the aggregates. When the cement powder mixed with water, it will form a paste. This paste will acts as glue to holds or bonds aggregates together. These bonds which are created will increase the strength of the cement. Clean, potable water are crucial to be used in this mix since any dirt, or unwanted chemicals in water may affect the properties of concrete. Either normal concrete or high strength concrete both has different mix design.

Admixtures are regularly incorporated in concrete mix to improve its durability as well as altering the fresh and harden properties of concrete, i.e. the time concrete takes to set and harden, or its workability.

The production of one ton of Portland cement produces about one ton of Green house gases (GHG).Plus, the manufacturing of Portland cement is the third most intensive energy process after aluminum and steel manufacturing, according to Malhotra (2004). By-products of Portland cement production are carbon dioxide and particulate matter which are all considered environmental pollutants that can harm human health.

Limestone is the essential ingredients in production of Portland cement. As limestone becomes a limited resource, employment and construction associated with the concrete industry will decline [9].

Due to inclining demand of concrete in the future, a new technique must be developed in order to create concrete with more environmental friendly materials and also with the minimal use of limestone.

Cement replacement materials are considered as an alternative in the concrete construction, in order to cater the limited resources of limestone. There are few types of cement replacement material that have been widely used; among them are silica fume, ground granulated blast furnace slag (GGBS), and pulverized fly ash (PFA), and rice husk ash (RHA). All these material are considered as pozzolanic materials which exhibit cementatious properties when reacted with calcium hydroxide at room temperature. These all can be used to supplement the use of cement in concrete mixtures while improving product durability.

All of those materials (GGBS, PFA and RHA) are considered as industrials waste (or by-products) which being produced in abundant. Therefore, the resources are not limited compared to limestone. The recycling of industrial by-products has been well established in the cement and concrete industries over the past decades [10].The use of coal fly ash in concrete began in 1930s, but volcanic ash has been used for mortar and concrete for several millenniums in Egypt, Italy, Mexico and India. The use of by-products such as rice husk ash, wood ash, silica fume and other pozzolanic materials in addition to creating more durable concrete and reducing greenhouse gas emissions [9]. This will also contribute to the improvement of air quality, reduction of solid wastes, and sustainability of the cement and concrete industry.

2.1 HIGH STRENGTH CONCRETE (HSC)

2.1.1 Definition of HSC

Concretes with compressive strength higher than 50 MPa are usually defined as high strength concrete (HSC), according to ACI committee 363. HSC are characterized by a low porosity and has a more uniform at the matrix-aggregate interface than normal strength concrete [11]. Strong interfaces enhance the strength and stiffness, although such concrete usually shows more brittle behavior. The production of high strength concrete requires more research and more attention to quality control then conventional concrete. The need of HSC has been in great demand especially in producing an early age service of concrete, for example opening a pavement at three (3) days. Other than that, HSC is advantageous in high rise building construction principally when there is a need to reduce the column sizes, thus it will increases the available spaces.

At the present time, a cubic yard of HSC generally costs more than a cubic yard of conventional concrete. HSC requires additional quantities of materials such as cement, fly ash, silica fume, high-range water-reducers and retarders to ensure that the concrete meets the specified performance. However the benefit which it brings will absolutely eliminate the cost of production. Conclusions for HSC, mix proportions must be selected to meet the specified performance criteria at a reasonable cost while using locally available materials.

2.1.2 Ingredients of HSC

The ingredients of HSC are basically the same as normal concrete (water, cement and aggregates). However, the mix proportions of materials are different. Mix proportions for high-performance concrete (HPC) are influenced by many factors, including specified performance properties, locally available materials, local experience, personal preferences, and cost. With today's technology, there are many products available for use in concrete to enhance its properties. Accordingly, there are many alternatives for mix proportions that will result in concrete with the desired properties.

Water-binder materials ratio; according to ACI 211.4R, many researchers have concluded that the most important variable in achieving high-strength concrete is the water-cement ratio [28]. However, most high strength concretes contain binding materials other than cement. Consequently, the water-binder materials ratio must be considered instead of the water-cement ratio where the binder materials include cement, fly ash, silica fume, RHA and ground granulated blast furnace slag (GGBFS) as appropriate. In general, as the water-binder materials ratio decreases, the concrete compressive strength increases.

Proper selection of the type and source of cement is one of the most important steps in the production of high-strength concrete. Variation in the chemical composition and physical properties of the cement affect the concrete compressive strength more than variations in any other single material. There is also optimum cement content beyond which little or no additional increase in strength is achieved by increasing the cement content. To achieve higher strengths, it is necessary to include other materials such as fly ash, silica fume, ground granulated blast furnace slag (GGBFS), or combinations of these materials [12].

For each concrete strength level, there is an optimum size for the coarse aggregate that will yield the greatest compressive strength per unit mass of cement. Commonly, a smaller size aggregate will result in a higher compressive strength concrete. On the other hand, the use of the largest possible coarse aggregate size is important in increasing the modulus of elasticity or reducing creep and shrinkage.

ACI 211.4R has reviewed that; fine aggregates with a fineness modulus in the range of 2.5 to 3.2 mm are preferable for high-strength concrete [28]. Concretes with a fineness modulus less than 2.5 mm may be sticky and result in poor workability and high water requirement.

2.1.3 Cement replacement materials in high strength concrete

Although concretes with compressive strengths greater than 6,000 psi (41 MPa) can be produced using only cement as the binding material, it is likely that these concretes will also contain a mineral admixture such as fly ash, rice husk ash (RHA), silica fume, or ground granulated blast furnace slag (GGBFS) to improve its workability.

In general, high performance concrete (HPC) is a cement-based concrete which fabricated to meet special performance requirements with regard to workability, strength, and durability. Those properties cannot always be obtained with techniques and materials adopted for producing conventional cement concrete [12]. A HPC using cement alone as a binder requires high paste volume, which often leads to excessive shrinkage and large evolution of heat of hydration, besides an increased in production cost [16]. A partial replacement of cement by mineral admixtures, such as, fly ash, rice husk ash (RHA) or ground granulated blast furnace slag (GGBS) in concrete mixes would help to overcome these problems and lead to improvement in the durability of concrete. This would also lead additional benefits in terms of reduction in cost, energy savings, promoting ecological balance and conservation of natural resources etc.

In additional, the strength development in high performance concrete is more complex in nature due to the combined physiochemical effects of pozzolans in concrete. The physical influence is in the refinement of pore structure of the cement paste, while the chemical phase consists of the pozzolanic reaction, which replaces C-H crystals with cementitious C-S-H gel [4, 13]. However, partial replacement of cement in concrete by pozzolans can produce an immediate dilution effect, which will cause early concrete strength to reduce in approximate proportion to the degree of replacement [13].

2.1.4 Chemical admixture in high strength concrete

Water-reducers or high-range water-reducers are essential in high-strength concrete to ensure adequate workability while achieving a low water-binder materials ratio for HSC

[27]. Retarding admixtures may also be used. The optimum dosage of an admixture or combination of admixtures should be determined by trial mixtures using varying amounts of each additive. It is also important to be sure that admixtures are compatible when used in combination.

2.2 POZZOLAN

2.2.1 Advantages of Pozzolan

Normal concrete is produced by mixing Portland cement with fine aggregates (sand), coarse aggregates (gravel or crushed stone) and water. Concrete solidifies and hardens after mixing and placement due to a chemical process known as hydration [15]. The water reacts with the cement, which bonds the other components together, eventually creating a stone-like material. Usually small amount of mineral and chemical admixtures were added to improve the concrete properties as well as its workability and durability.

Mineral admixtures are siliceous or non-siliceous and aluminous materials which in themselves possess little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties [16]. Most of mineral admixtures are inorganic materials that have pozzolanic or latent hydraulic properties. These very fine-grained materials are added to the concrete mix to improve the properties of concrete or as a partial replacement of Portland cement. Pozzolans improve strength because of their small particles (less than cement) which help to provide a finer pore structure in concrete [17]. Rice husk ash (RHA) is one example of an active mineral admixture.

2.2.2 Pozzolan reaction on concrete

It has been recognized that pozzolanic additions lead to important changes in fresh and hardened concrete, which depend on the mineral admixture type and content as well as on other mix components. Some of the important benefits are:

i. Increase compressive strength

The pozzolanic reaction between natural pozzolan and calcium hydroxide happens after the C_3S and C_2S in the cement begins to hydrate. At the early stage of curing, usually natural pozzolan substituting Portland cement mixture is slightly lower than reference OPC (Ordinary Portland Cement) in regard to compressive strength. As time goes by, natural pozzolan continues to react with the calcium hydroxide; Ca (OH_2) produced by cement hydration and increases the compressive strength by producing additional C-S-H gels [17]. The pozzolanic reaction continues until there is no free calcium hydroxide available in the mass and the compressive strength exceeds the reference OPC by 30-40% [18].

ii. Reduced Permeability and Voids

Experts have widely agreed for decades that the use of pozzolana, or supplementary cementing materials, can reduce concrete permeability by 7 to 10 times [19]. In particular the mechanism of pozzolana in this role can be viewed as having two principal aspects. First, the use of quality pozzolan i.e. finer, high silica content will result in a denser pore structure in the cement paste matrix. Second, the chemical reaction of lime crystals to form binders has a direct effect of increased paste density, reduced porosity over time, and will enhance the matrix chemical resistance to many aggressive species that could harm the durability of concrete.

2.3 ADMIXTURE

2.3.1 Introduction to admixture

According to ASTM C125, admixture are material other than water, aggregates and cement, used as an ingredients of concrete which added before or during mixing [29]. The general purpose of adding admixture are; to increase plasticity of concrete without rising the water content, reducing bleeding and segregation of concrete, retard and accelerate the setting time, to accelerate the rate of strength development at early ages, to reduce the heat of evolution and to increase the durability of concrete to specific exposure conditions. Admixtures are divided into two categories; chemical and mineral. Chemical admixtures are normally added in small amounts, usually dissolved in the mixing water. The common used chemical admixtures are water reducers or plasticizers, super plasticizers, retarding admixtures, accelerating admixtures and air-entraining agents. The used of those chemical admixtures are entirely depending on the desired end product. Mineral admixtures refer to pozzolan as discussed thoroughly in subtopic 2.3.3. Pozzolan normally posses natural qualities in contributing to strength and refined microstructure of mixture, that can enhance the quality and long-term performance of concrete.

2.3.2 Chemical admixture : Water reducers and Superplasticizers

These are surface active chemicals, also known as surfactants. Without water reducer or super plasticizer, once cement particles in contact with water, they tend to flocculate due to high surface tension of water. The flocculated structure of the cement paste particles could trap a certain amount of water, which then no longer available to lubricate the mix. The addition of water reducers and superplasticizers could deflocculate and disperse the cement particles. As a result, more water is available for lubricating the concrete mix and the flow properties of concrete, as can be seen by the increase in workability (slump, flow, compacting factor and vebe).

Verbeck (1968) has reported that, superplasticizers are linear polymers containing sulfonic acid groups attached to the polymer backbone at regular intervals [30]. Most of the commercial formulations for the superplasticizers belong to one of four families:

- Sulfonated melamine-formaldehyde condensates (SMF)
- Sulfonated naphthalene-formaldehyde condensates (SNF)
- Modified lignosulfonates (MLS)
- Polycarboxylate derivatives

The sulfonic acid groups are, according to Mindess and Young (1981), responsible for neutralizing the surface charges on the cement particles and causing dispersion, thus releasing the water tied up in the cement particle agglomerations and thereafter reducing the viscosity of the paste and concrete [5].

2.3.3 Mineral admixture : Rice husk ash (RHA)

Rice husk ash is a well-known mineral admixture for concrete. Mineral admixtures refer to finely divided materials, which posses pozzolanic or/ and cementatious properties, when used as concrete ingredients. They can be used to partially replace part of cement, or as an additive to cement. In either case they are normally incorporated to the batch shortly before or during mixing. RHA is among the latest discovery regarding pozzolans, but enormously promising on a global scale. The pozzolanic characteristics of ash are dependent on the chemical composition of the material, burning temperature, burning time, burning environment and burning method [22, 23].

In order to obtain an ash with high pozzolanic activity, the material should have high silica content. The silica should be in non-crystalline state, highly microporous and cellular structure [4]. Grinding RHA helps to increase its pozzolanic activity by increasing the surface area.

Chemical compositions of rice husk are similar to many common organic fibers. This composed of;

(1) Cellulose (40 – 50 %)
(2) Lignin (25 – 30%)
(3) Ash (15 – 20%)
(4) Moisture (8 – 15%)

After burning at a suitable temperature and time (600 – 700 °C in 2 hours), in an industrial furnace, according to Hwang and Chandra (1997), the rice husk ash is consists of [4];

(1) 90 – 95 % SiO_2
(2) 1 - 3% K_2O and more than 5% of unburnt carbon

2.4 RICE HUSK ASH (RHA)

2.4.1 Combustion: Different process

Rice husk ash is produced by combustion of the husk. Few types of combustion method that have been studied are discussed as below:

a) Open-field burning

This uncontrolled burning method is banned in many countries, other than producing poor quality of ash, the structure are highly crystalline which illustrate a low reactivity.

b) Fluidized-bed furnace burning

This furnace is designed for control burning of rice husk [14]. Time-temperature parameter in the burning operation is maintained with a close control. The heat of combustion is utilized to produce steam or electricity. Highly pozzolanic rice husk ash is produced by maintaining temperatures between 500 – 700 °C for less than one minute. Chemical analysis on the ash samples produced showed 80 – 95% SiO_2, 1 – 2% K_2O, and 3 – 18% unburned carbon.

c) Industrial furnace

The silica content produced by this method is depending upon the combustion efficiency of the furnace. Usually, the silica content of RHA produced may be in the range of 90 – 95% with the residual carbon as the main remaining ingredient. It is possible to produce RHA with silica in amorphous and cellular form. Thus, RHA produced is highly pozzolanic.

2.4.2 Grinding

Hwang and Chandra (1997) has suggested that, the quality of RHA are also depends on the degree of grinding other than the method of ash incineration [4]. Bouzoubaa and Fournier (2001) have done a quite fine research on the optimum grinding time of RHA. They found that the water requirement of concrete increased because of the fineness of RHA, and yet, 7-days strength of concrete improved marginally with increase of grinding time [31]. To produce a fine powder, and ball or hammer mills are usually used. Good results were obtained by Chopra (1979), where in his study, RHA obtained from burnt rice husks (which used as fuel for boilers resulting in crystalline RHA) were used to develop masonry cement [32]. Crystalline ash is harder and will require more grinding in order to achieve the desired fineness. Fineness similar to or slightly greater than that of PC is usually recommended for pozzolanas although some have been ground considerably finer.

2.4.3 Characteristic of concrete containing RHA

The development and use of rice husk ash in cement and concrete manufacturing is not new. Many researches have been published concerning its influence on the concrete behavior. It has proven literally that concrete with a 10% substitution of Portland cement by RHA indicate an excellent performance of concrete when compared to normal concretes [21]. Some of the effects of RHA to concrete are discussed as below;

i. Workability of fresh RHA concrete

Small addition of RHA may be helpful for improving the stability and workability of concrete by reducing the tendency towards bleeding and segregation [24]. This is mainly due large surface area of the ash which in the range of 50 to 60 m^2/g [17]. Large addition of fine RHA particles tend to absorb a great amount of water, hence producing dry, unworkable concrete mix.

ii. Initiate early strength development of concrete

RHA also tends to shorten the setting time due to the water adsorption ability of the cellular form of RHA [4]. Therefore, the reduction of water-to-cement ratio may cause an increase in the early strength development.

iii. Increase compressive strength of concrete

The incorporation of RHA in concretes produced an increased in compressive strength, particularly for the lower water/binder ratio concretes. Addition of RHA can affect both strength and permeability by strengthening the aggregate-cement paste interface and by blocking the large voids in the hydrated cement paste through pozzolanic reaction as shown in Figure 2.1 below [4].

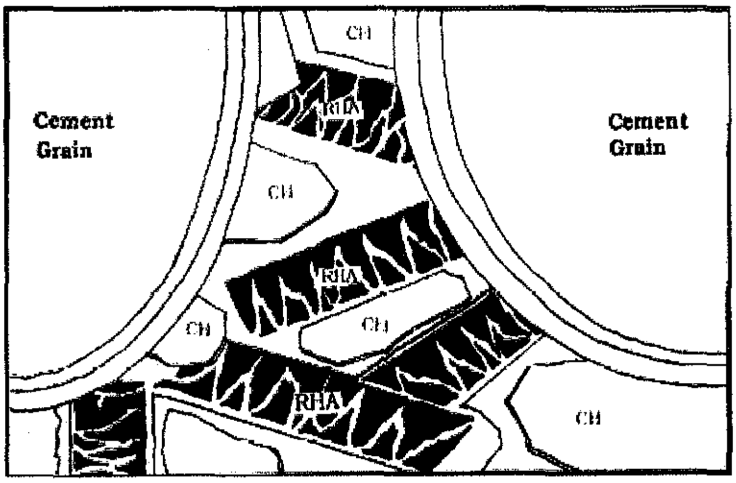

Figure 2.1: Mechanisms of void filling and transition zone strengthening effects of RHA [4].

2.5 USED ENGINE OIL (UEO)

2.5.1 Physical properties of Engine oil

Most motor oils are made from a heavier, thicker petroleum hydrocarbon base stock derived from crude oil, with additives added as needed to improve the properties [22]. One of the most important properties of motor oil in maintaining a lubricating film between moving parts is its viscosity. Used engine oil (UEO) basically has an oil-like feature, usually black in color and really viscous.

2.5.2 Chemical properties of Engine oil

Before it was being used, the engine oil consists of base lubricating oil with the complex mixture of hydrocarbon (80 – 90% by volume) and performance – enhance additives (10 – 20 % by volume) [23]. This engine oil composition are altered during use because of the breakdown of additives, contamination with product of combustion, and the addition of metals from wear and tear of the engine. Therefore, it is difficult to generalize the composition of waste oil in exact. However, it is recognized that the major components are aliphatic and aromatic hydrocarbon (such as phenol, naphthalene, benz (a) antracene, benz (a) pyrne and fluoranthene) [23].

2.5.3 Characteristic of concrete with used engine oil (UEO)

Research on effect of used engine oil to fresh and hardened concrete has previously been done by Hamad et al. (2003), which he compares the performance of used engine oil and chemical air-entraining admixture in normal strength concrete. The results are very impressive where, the used engine oil acted as a chemical plasticizer improving the fluidity and almost doubling the slump of normal concrete mix.

From their investigation, it was found on the hardened property, the used engine oil mix has resulted in average losses of 17 % in the values of the splitting tensile strength.

However, the concrete compressive strength is maintained throughout compares to chemical air-entraining admixture which caused approximately 50% loss in compressive strength at all ages [6].

2.6 CONCRETE ASSESSMENT

Properties of concrete are measured at fresh as well as hardened state. Properties at fresh state are significant to control the performance of concrete in the hardened state.

2.6.1 Slump Test

The slump test is the most common test for workability. The slump test involves hand placing an amount of fresh concrete into a metal cone and then measuring the distance the fresh concrete falls when the cone is removed. The decrease in the height of the slumped concrete is term as slump. It is measured to the highest point according to BS1881: Part 102: 1983. A stiffer mixture will have a low slump value. Concrete with high workability gives a higher slump value.

2.6.2 Compressive Strength Test

Concrete is most often known by its compressive strength. This is because concrete is much stronger in compression than it is in tension and thus, is frequently used in compression.

Generally, normal concrete has a compressive strength between 20 and 35 MPa (3000 and 5000 psi) (ACPA, 2001). High-strength concrete is usually defined as concrete with a compressive strength of at least 41 MPa (6000 psi). High-strength concrete has been designed for compressive strengths of over 140 MPa (20,000 psi) for use in high rise building applications especially.

The compressive strength is calculated from the failure load which result from breaking cubical concrete specimens in a compression-testing machine; then the failure load is divided by the cross-sectional area resisting the load and recorded in the units of pound-force per square inch (psi) in US Customary units or Mega Pascal (MPa) in SI units.

2.6.3 Porosity Test

The original packing of the cement, mineral admixtures, and the aggregate particles; the water-to-solids ratio; and the conditions of curing are all related to porosity. According to Mehta (1993), permeability of concrete, is also influenced by two primary factors: porosity and interconnectivity of pores in the cement paste and micro-cracks in the concrete, especially at the paste-aggregate interface [33]. Nevertheless, porosity and interconnectivity are controlled for most part by the water-binder ratio, degree of hydration, and the degree of compaction.

2.6.4 Split Tensile Test

Although concrete is not nearly as strong in tension as it is in compression, concrete tensile strength is important in most concrete applications. Tensile strength is typically used as a concrete performance measure because it best simulates tensile stresses at the bottom of the concrete surface course as it is subjected to loading, where tensile cracking of concrete limits the usefulness as well as life of structures [36]. It is difficult to directly measure because of secondary stresses induced by gripping a specimen so that, it may be pulled apart. Therefore, one way is to measure the tensile stresses by splitting tension test.

The split tension test is done by casting a standard cylinder of concrete specimens. A diametral compressive load is then applied along the length of the cylinder until it fails. Because concrete is much weaker in tension than compression, the cylinder will typically fail due to horizontal tension and not vertical compression.

CHAPTER 3

METHODOLOGY

3.0 RAW MATERIAL SELECTION

For making high strength concrete, it is essential to select proper ingredients. The basic ingredients for concrete are water, cement and concrete and the admixtures added are MIRHA and UEO. For cement, ASTM Type I, normal Portland cement was used in this project. Table 3.1 shows the chemical compositions of normal original Portland cement (OPC) Type I.

Table 3.1: Physical and Chemical Properties of OPC Type 1. (Adapted from Cement Industries of Malaysia Berhad (CIMA))

Modulus	Lime Saturation Factor	0.96
	Silica Modulus	2.37
	Iron Modulus	1.58
Compressive Strength (N/mm^2)	3 Days	38
	7 Days	46
	28 Days	56
Chemical Ingredients (%)	SiO_2	19.98
	Fe_2O_3	3.27
	Al_2O_3	5.17
	CaO	63.17
	MgO	0.79
	SO_3	2.38
	Total Alkalis	0.90
	Insoluble Residue	0.2

Aggregate occupies 60 to 70% of the concrete volume and plays a significant role in achieving the properties of concrete. Gravel as course aggregate used was 14 mm nominal maximum gravel. Sand as fine aggregate used was natural sand having a 3.35 mm nominal maximum size. Both aggregates conforming to BS 882: 1992.

The water requirement for concrete producing must be free from any dirt and/or chemical. Tap water is the most suitable choice to satisfy the condition.

The rice husks used in this project were taken from rice milling plant Bernas, Malaysia. The Microwave Incinerated Rice Husk Ash (MIRHA) was produced by microwave incineration in the UTP laboratory. Further information on burning procedure is stated further in subtopic 3.1.

Used engine oil which being used for this study comes from motor-vehicle transport i.e. car, van, and lorry. It was obtained from the automobile workshop in Tronoh, Perak. The chemical composition of both MIRHA and UEO are shown in the Table 3.2.

Table 3.2: Chemical compositions of MIRHA and used engine oil

Chemical Composition	MIRHA (%)	Used engine oil (%)
SiO_2	88.6	-
K_2O	5.25	
MgO	0.851	
Al_2O_3	0.110	
Fe_2O_3	0.114	0.43
CaO	0.988	15.9
SO_3	0.501	37.0
P_2O_5	-	8.95
ZnO	-	17.7
Cl^-	-	15.9

3.1 BURNING PROCEDURE OF RHA

Rice husk ash that is used in this study is produced by microwave incineration process. The microwave incinerator used for the combustion process of the rice husk is shown in the Figure 3.1. The microwave incinerator is located at Block I, UTP. In order to do the burning process, supervisions by lab assistant are required. The burning temperature for the incinerator was set up in two (2) phases at different temperatures and certain period of time. Table 3.2 shows the relative temperatures and their specific time for burning process.

MIRHA that is produced are grayish in color after being burnt twice. The first incineration is at 150°C and continues to burn at 500°C after it was cooled down. This temperature is the proven temperature which will ensure the silica components in the ash is not destroyed. After MIRHA being cooled down, the ashes are ground using LA Abrasion Machine three (3) times with 1000 cycles each. The allowance size of the MIRHA is below 212 μm.

Table 3.3: Temperatures and times for microwave incinerator for MIRHA

Phase	Temperature	Duration	Remarks
Phase I	25° C - 150° C	1.5 hours	To remove the carbon and other volatile materials
Cooling	25° C	(until it reached an ambient temperature)	To ensure excess heat is not generated that can cause crystalline MIRHA for the next burning stage
Phase II	25° C - 550° C	2.5 hours	To achieve amorphous silica content of MIRHA.

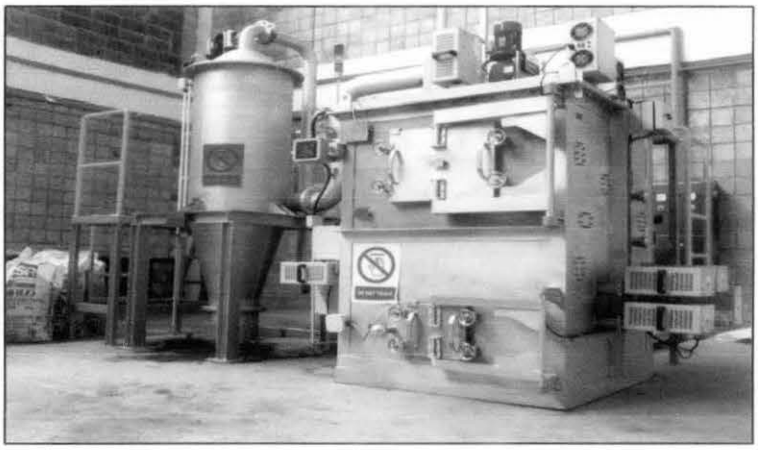

Figure 3.1: Microwave Incinerator in UTP laboratory.

3.2 CONCRETE MIXING

3.2.1 Mix Proportions

The proportions of the concrete mixtures are summarized in Table 3.3. A total of 9 mixes was made from three different water-binder ratios (w/b) i.e. 0.40, 0.37 and 0.34. Each type of w/b has a control mix contains only 10% of MIRHA, and two other mixes containing 3% and 4% of UEO. Water and admixtures was measured in percentage by weight proportion of cement used.

Table 3.4: Mix proportion for concrete samples

Mix Type	w/b	UEO (%)	OPC (kg/m^3)	RHA (kg/m^3)	FA (kg/m^3)	CA (kg/m^3)
M1	0.40	0	500	50	690	1150
M1/UEO-3		3				
M1/UEO-4		4				
M2	0.37	0	550	55	670	1120
M2/UEO-3		3				
M2/UEO-4		4				
M3	0.34	0	600	60	650	1090
M3/UEO-3		3				
M3/UEO-4		4				

3.2.2 Mixing Process

All concrete mixtures were mixed for five minutes in a laboratory counter-current mixer. There are altogether six (7) mixes being produced for this project. Procedures for concrete mixing are:

1. Add coarse and fine aggregates
2. Mix aggregates for 25 seconds in rotator.
3. Add half amount of total water needed into the mixture.
4. Mix the mixture for 1 minute.
5. Leave the mixture for 8 minutes.
6. Add all cement and mix for 1 minute.
7. Add remaining water and mix for another 1 minutes.
8. Pour the mixture of concrete into the moulds 150 mm x 150 mm x 150 mm provided.

[Ref: BS 8110]

Concrete cubes were cast in standard steel mould of dimensions 100x100x100mm. Concrete cylinders were cast mould in standard size of 100mm diameter and 200mm height of steel cylinder moulds. Concrete in moulds was laid in few layers depending on the mould thickness of approximately the same thickness for each layer. After laying each layer, compaction was done by applying vibration according to the specifications defined in BS 8110: 1997. Plain concrete planks of 400x400x40mm dimensions were cast in wooden moulds, 55 mm diameter cores were drilled out after curing for 28-days in water bath for porosity measurement from the planks.

After pouring the concrete into the mould, they are left to dry for 24 hours. After that, they will be removed form their mould and moved into the curing tank until required for testing for 3, 7, 28 and 90 days.

The main purposes of putting the molded concrete into the curing tank are; first, to assist the continuation of hydration process deep within the cubes, which will increase the concrete optimum strength. Secondly, is to reduce the heat of hydration produces which might cause cracks if the cubes are not properly cured.

3.3 TESTING PROCEDURE

3.3.1 Slump Test

This test was conducted after each mix of concrete; that is when the concrete is still in fresh state. The procedure for Slump Test is as below:

1. Invert the cone (see figure 3.3 and 3.4 below).
2. Fill it up with 3 layers of equal volume.
3. Each layer is tamped 25 times with the rod.
4. After that, the surface will be scarped off.
5. The cone than carefully lifted off.
6. The slump is measures. True slump and shear slump are acceptable.

[Ref: BS1881: Part 102: 1983]

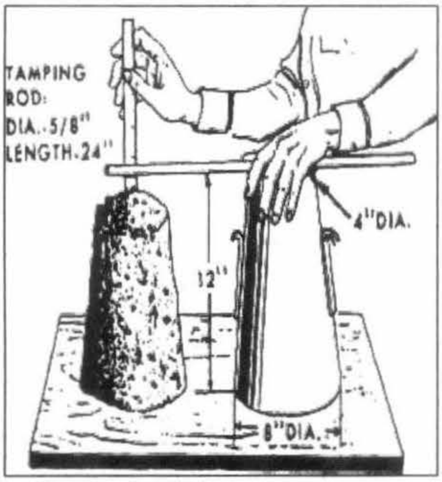

Figure 3.2: The measurement of slump

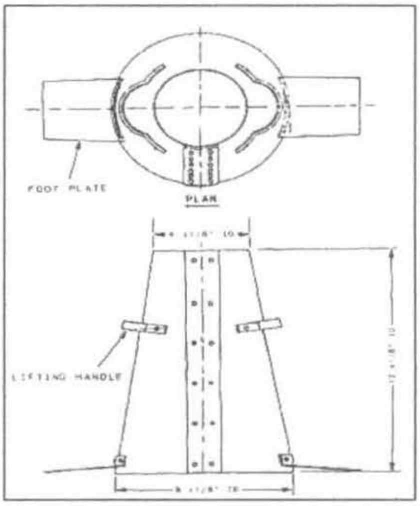

Figure 3.3: The dimensions of cone used in slump test

3.3.2 Compressive Strength Test

The compressive strength test of concrete cubes will be conducted at ages 3, 7, 28 and 90 days of curing. Compressive test would be done using the Universal Testing Machine that complies with the BS 1610 standard (refer Figure 3.4). Load is applied and increased continually without shock at a nominal rate within the range 0.2 N/mm^2 to 0.4 N/mm^2 until no greater load can be sustained (until the concrete cube fails). The maximum load applied to the cube is recorded and compared with another result form different ages, so that the strength development of the cube can be described.

Figure 3.4: Compressive strength machine

3.3.3 Split Tensile Strength Test

For the splitting test for concrete, the test will be conducted at ages of 28-days on the cylinder concrete samples. As compressive strength test, this test will be done by the same Universal Testing Machine. The standard for this test is ASTM C 496. The cylinder concrete samples will be inserted in the compression machine horizontally so that the compression could be applied uniformly along two opposite plates. A metal pad will be holding the concrete samples while the test takes place to equalize and distribute the pressure. The compression will end until the concrete fails, which causing the cylinder to split into halves. The maximum loading at failure is recorded.

3.3.4 Total Porosity Test

As mention earlier, three (3) 55mm diameter discs will be cored-out from concrete planks at the age of 28 days. The specimens were vacuum saturated in water, at fully saturated condition. The vacuum saturation apparatus used in this investigation is similar to the method developed by RILEM (1984) for measuring the total porosity. Figure 3.7 shows the diagram of the apparatus.

Then, the specimens were weighed in the air (W_A) and in the water (W_W). Finally, they were dried in an oven at 105°C to constant weight (W_D).

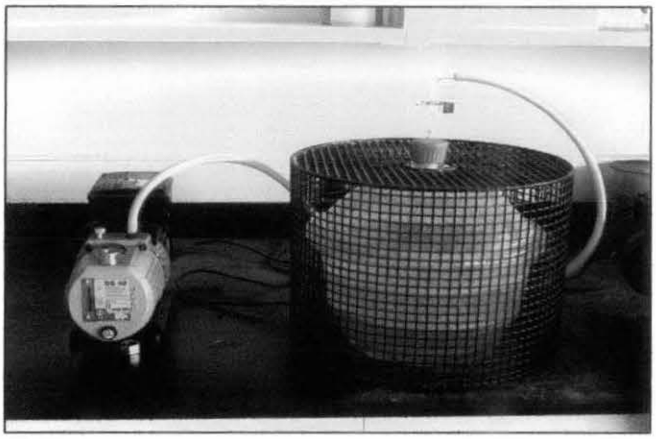

Figure 3.5: Vacuum saturation apparatus

The total porosity, P of concrete samples is calculated using the following equation:

$$P = \frac{W_A - W_D}{W_A - W_W} 100 \qquad (3.1)$$

Where:

P = Total porosity (%)

W_A = Weight of saturated samples measured in the air (g)

W_W = Weight of saturated samples measured in water (g)

W_D = Weight of oven dry samples measured in the air (g)

3.4 HAZARD ANALYSIS

Most of the project work was carried out in the concrete laboratory in Building 14, UTP. Safety measures that were taken into consideration throughout the laboratory works are provided in Table 3.5.

Table 3.5: Safety measures taken throughout the laboratory works

Equipment	Basic steps	Potential hazards /accidents	Recommended safe job procedure
Concrete mixer	Opening the mixer heavy lid	The heavy lid might fall down on the feet – broken leg	Do not work with the mixer individually –team work
	Unloading concrete ingredients	Backache – long term may cause bone crack	Take proper precaution while lifting heavy objects
	Switching on and off the mixer	Electrocuted – water might interfere the life wire	Ensure safety (e.g. No wet hands)before operating the machine
Universal Testing Machine	Loading of samples in place	Heavy concrete drop Loading steel drop Injured user hands	Wear proper protective safety shoes Always wear gloves when handling concrete Take proper measure when lifting heavy objects
	Running the compression test	Chips of concrete flying and might hit body	Always close cover and lock Wear proper lab coat/safety jacket and safety goggles
Lab coring machine	Loading samples in place	Heavy concrete drop Injured user hands	Wear proper protective safety shoes Always wear gloves when handling concrete
	Running of coring test	Chips of concrete flying and might hit body	Always close cover and lock Wear proper lab coat/safety jacket and safety goggles
Microwave incinerator	Loading in the husk into the incinerator Burning of the Husk Cooling down	Small particles of rice husk might enter our breathing systems	Proper mask and gloves needed to be worn all the time in the lab

CHAPTER 4

RESULTS AND DISCUSSION

4.0 CONCRETE SAMPLE ANALYSIS

4.1 Analysis on Fresh concrete

4.1.1 Slump test result and discussion:

The slump test is measured on the newly mixed concrete (within five (5) minutes after obtaining the final portion of the composite sample). Figure 4.1 below shows the variability of results obtained from slump test conducted on concrete samples in their fresh state. The slump values observe in control mix do not shows any much changes for the three different w/b ratios. However, slump values of UEO mixtures of 3% and 4% shows an improvement, compared to the control mix (CM). Basically, the results suggest that slump value decrease as w/b ratio reduced from 0.4 to 0.34%. Addition of 4% UEO to MIRHA concrete mix shows the highest increment of slump value to at least 60% compare to the 3% UEO and control mix at 0.4 w/b ratio.

Generally, concrete containing RHA require more water for a given consistency, due to the adsorptive character of cellular particles of MIRHA [17]. Though, the addition of UEO has able to improve small percentage of workability in MIRHA concrete.

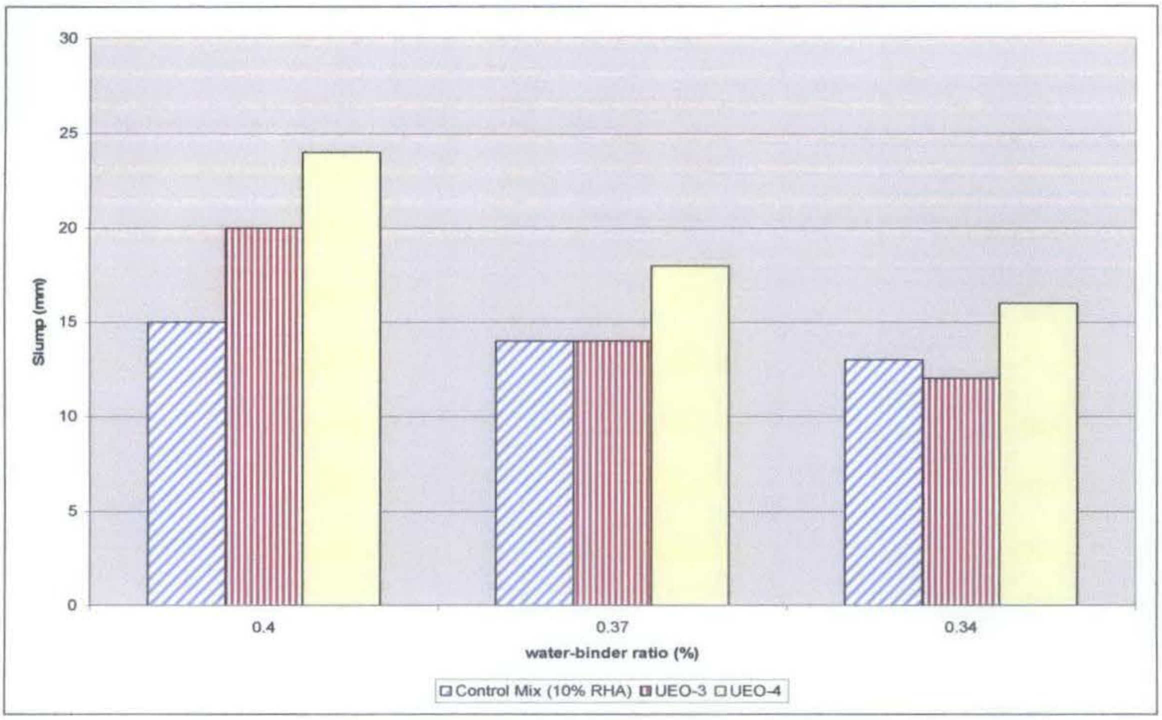

Figure 4.1: Slump test result for each mixture compare with the control mix of each w/b ratio

4.2 Hardened Properties of Concrete

4.2.1 Compressive Strength Test Result and Discussion:

Three cubes are prepared for each mixture to ensure validity of result obtained. Results of the test for different water-binder ratio are shown in the Figure 4.2, 4.3 and 4.4 below. In order to evaluate the UEO effect to the compressive strength of concrete, compressive strength of control mix is compared with the compressive strength of 3%UEO or 4%UEO.

From Figure 4.2, the graph shows that the compressive strength for mixes of 0.4% w/b varies as the used engine oil was added to the mix. CM shows a slow rate for the early stage development as compared to the UEO mixtures. Both mixes demonstrate a rapid strength development with higher strength achieved as the curing age passed through 28-days, which is better than the CM of the same w/b ratio.

The same pattern of graph is developed for the compressive strength result of mixes of 0.37% w/b (see Figure 4.3). However, no clear trend on early strength development can be seen as the graph demonstrates an equivalent rate of strength development for all the mixes for this w/b ratio. Still, the addition of UEO (for both percentages) in MIRHA concrete give rise to the compressive strength as they reached the 28-days of curing age.

Moreover, Figure 4.4 has shown a quite outstanding achievement for the compressive strength development of concrete mix with RHA and UEO even though the early strength development for both mixes was slower rate compare to the control mix. The rate of early strength development for CM shows a rapid progress compare to both UEO mixtures. Yet, in the later stage, both UEO mixtures tends to quickly develop in strength, which able to outdone the CM compressive strength at 28-days.

MIRHA has the ability to contribute for strength of Portland cement (PC) in the early ages of 1 - 3 days [4]. From the results obtained, rate of strength development in MIRHA concrete at the early ages increase as the w/b ratio reduced. Addition of 3% and 4%UEO in MIRHA concrete initially reduced the ability of MIRHA concrete to assist in the early strength development. Nonetheless, both UEO mixtures managed to develop rapid growth in the later stage and able to increase the MIRHA concrete strength. Both percentage of UEO (3% and 4%) added in MIRHA concrete show equivalent value of strength at 28-days for all the w/b ratios. Greatest effect of UEO in strength was observed in the 0.34 w/b mix where the strength of MIRHA concrete was improved by 20% for both UEO mixtures.

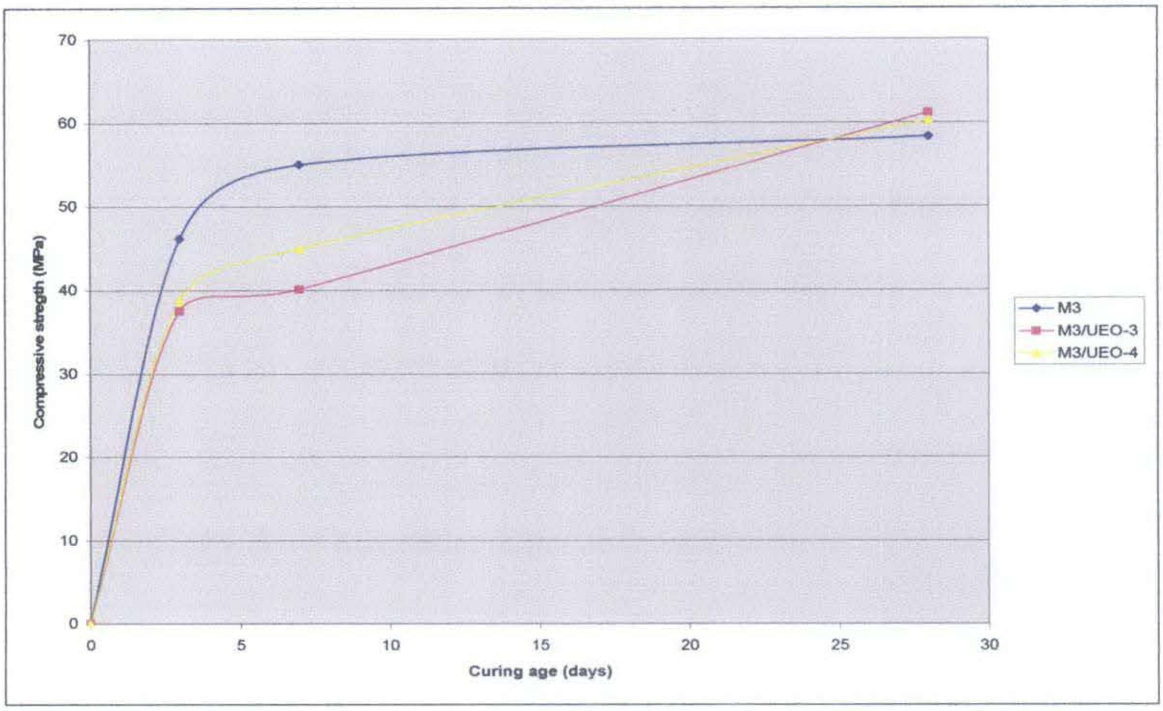

Figure 4.4: Compressive strength for 0.34 % of w/b mix

*M3 – 10% MIRHA Sample, M3/UEO-3 – 10% MIRHA and 3% UEO Sample, M3/UEO-4 – 10% MIRHA and 4% UEO Sample

4.2.2 Split Tensile Test Result and Discussion:

Result for the 28-day split tensile test is presented in the Figure 4.5 below. The results were compared with the control mix of 10% MIRHA. The addition of 4%UEO obtained the highest tensile strength (about 21% increment) against MIRHA concrete. Whereas, 3% UEO in MIRHA concrete also shows growth of tensile strength; which is higher (highest value at 16%) than CM as w/b ratio decreased.

According to Naik et al. (1995), the splitting tensile strength of pozzolan concretes is higher than that of normal concrete, since the grain and pore refinement of concretes resulted from the very high fineness of particles and pozzolanic reaction of the ashes. The MIRHA fineness may has been contributing into the high value of concrete split tensile value which has additional of UEO. The result has indicated that UEO able to increased the modulus of elasticity on MIRHA concrete, which giving stiffness to MIRHA concrete.

However, as the w/b goes below 0.40, the tensile strength reduces. Generally, the strength increases as the w/b reduces. However, this is not happen in this experiment as it went below 0.40, the split tensile strength increases. Some errors might occur during this experiment. As the w/b lower than 0.40, an inaccuracy on materials might be occurred. For instance, the aggregates used are usually assumed to be saturated surface dry. However, due to humidity of Malaysia, those aggregates might be too dry, thus tends to absorb as much water, which then lead to disturbance on the concrete strength, where the concrete will not be fully hydrated. Therefore, w/b 0.40 is chosen to be the optimum value for concrete.

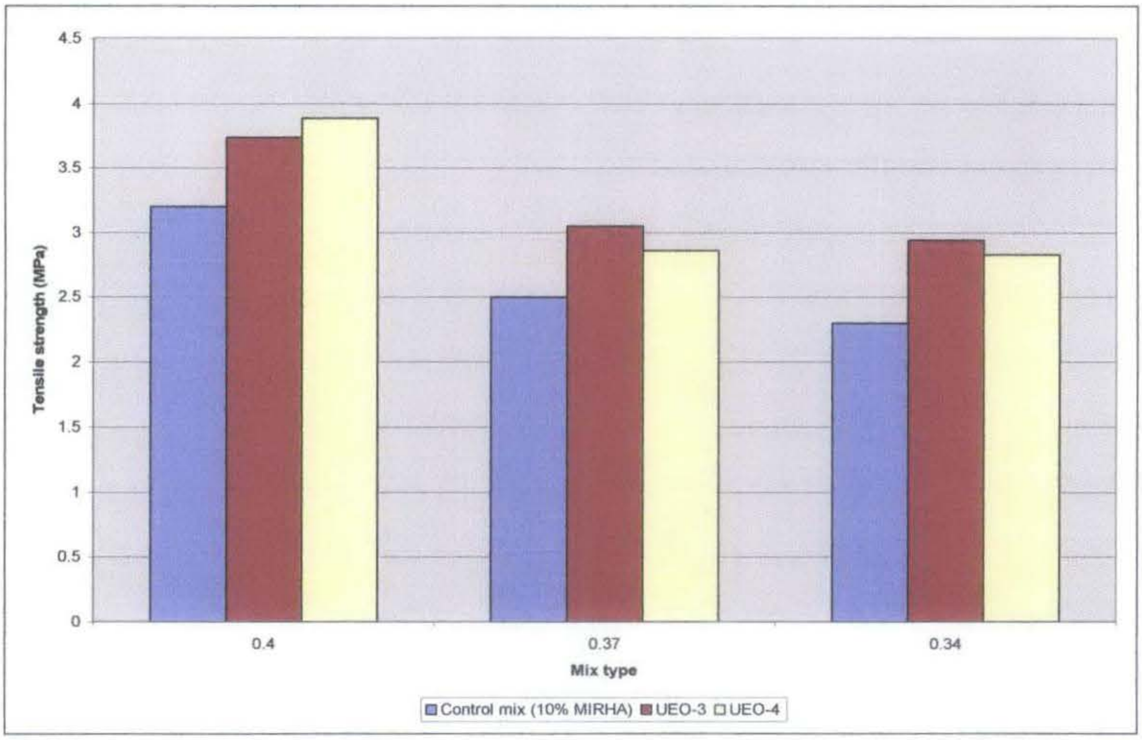

Figure 4.5: The Split Tensile result for M1, M2 and M3 at 28-days of curing age

4.2.3 Porosity Test Result and Discussion:

Total porosity of hardened concrete is an indicator of quality, durability and strength. As hydration process takes place, with respect to the increasing number of curing age, the total porosity of concrete reduces. The lower the porosity of concrete would be a sign of better and durable concrete.

The result on Figure 4.6 shows the porosity test result for three MIRHA concrete mixes. CM concretes indicate increment as the w/b reduced.

It has been reported that at early age of curing (7 and 28 days) supplementary cementitious materials are more porous than the plain cement paste and the pore size distributions finely distributed, but at the later ages (90 days) this may be reversed. They have also reported that pozzolanic materials increased the porosity and reduced the pore structure [19]. The small RHA particles improved the particle packing density of the blended cement, leading to a reduced volume of larger pores. The same theory applies to both MIRHA concretes with UEO results. Reduction of porosity is observed in both mixtures, but not much difference can be seen on the porosity value different effect with 3 and 4%UEO. Even though the addition of UEO does not shows an obvious changes to the concrete's porosity, it somehow shows the ability to assist in reducing the porosity of the concrete by almost 10%. This observation suggests that UEO could enhance the durability of MIRHA concrete.

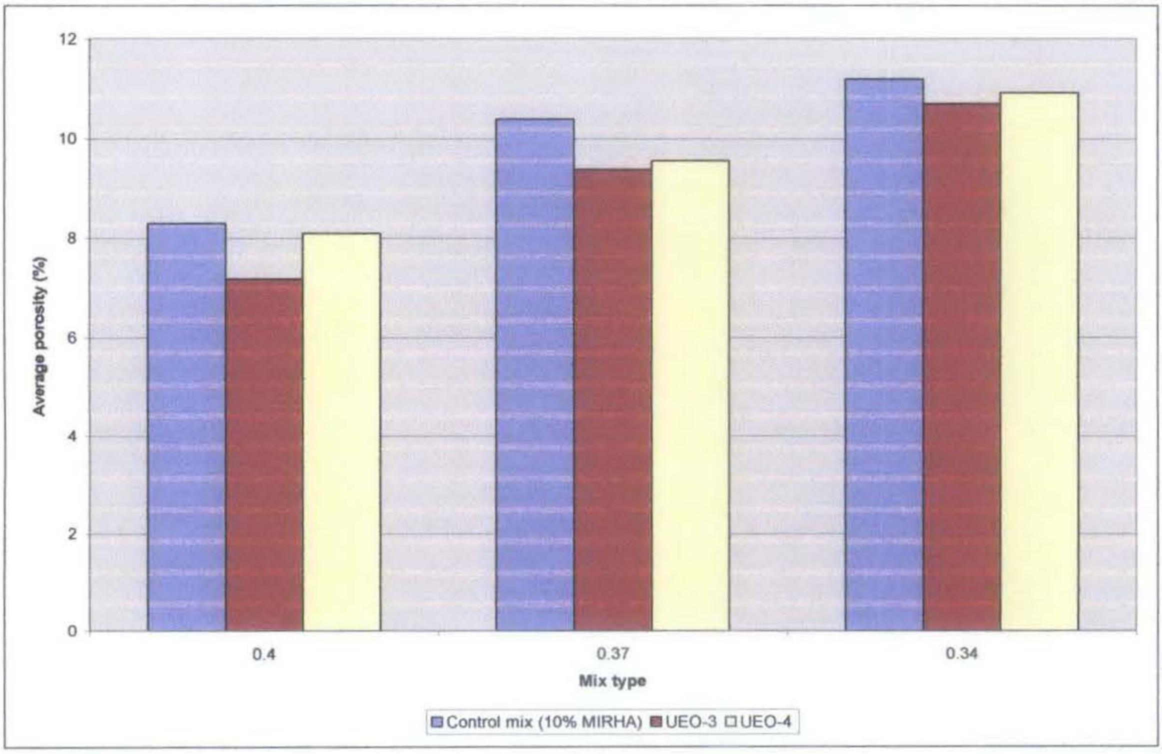

Figure 4.6: The Porosity test result for M1, M2 and M3 at 28-days of curing age

CHAPTER 5

CONCLUSION

5.0 CONCLUSION

The main objective of this project includes creating an effective way to dispose agricultural and industrial waste by incorporating them into high strength concrete manufacturing. The results have shown convincing development of strength for the concretes. As for the overall conclusion of this project are as follows:

1. Able to produced high strength concrete with the highest strength of approximately 62 MPa with the combination of MIRHA and used engine oil.
2. The slump values for all MIRHA concrete samples of the three w/b mixes shows a superplasticizer effect on improving workability (almost 60%) by the addition of used engine oil.
3. Effect of used engine oil is seen on the hardened concrete properties, where the used engine oil helps in improving the strength development of the concrete by 20%.
4. As for the split tensile strength, the addition of used engine oil assists on strengthening the tensile strength bond of the MIRHA concrete up to 52% with addition of 3%UEO.
5. The porosity of the concrete has shown an improvement as used engine oil helps in lowering almost 10% of the MIRHA concrete porosity.

REFERENCES:

[1] Th. Mang, W. Dresel (2007), Lubricants and Lubrication, 2nd Ed. Edited Copyright 4 2007 WILEY-VCH Verlag Gmbh & Co. Kgaa, Weinheim ISBN: 978-3-527-31497-3

[2] Naik T R. (2005), Sustainability Of Cement And Concrete Industries, Center For By-Products Utilization, CBU-2004-15, and REP-562.

[3] Naik, TR, Kraus, R N, Ramme, B W, and Siddique, R. (2003), Long-Term Performance of High-Volume Fly Ash Concrete Pavements, ACI Materials Journals, Vol. 100, No. 2, Pp. 150-155

[4] Hwang, C. L. And Chandra S. (1997), The Use of Rice Husk Ash in Concrete, Waste Materials Used in Concrete Manufacturing By Chandra S., Technology, Pp.184-230.

[5] Mindess S, Young J (1981). Concrete, Englewood Cliffs, New Jersey: Prentice-Hall, Inco

[6] Bilal S. Hamad, Ahmad A. Rteil, Mutassem El-Fadel (2003), Effect of Used Engine Oil on Properties of Fresh and Hardened Concrete, Construction And Building Materials 17, pp.311-318.

[7] El-Fadel, M., Khoury, R. (2001), Strategies for Vehicle Waste-Oil Management: A Case Study Resources, Conservation and Recycling 33 (2), Pp. 75-91.

[8] Struble L., Godfrey J. (2004), International Workshop on Sustainable Development and Concrete Technology

[9] Malhotra, V. M.(2004), Role of Supplementary Cementing Materials And Superplasticizers in Reducing Greenhouse Gas Emissions, Proceedings of ICFRC International Conference on Fiber Composites, High Performance Concrete, And Smart Materials, Chennai, India, Pp. 489-499.

[10] Mehta, P. K. (2002), Greening of the Concrete Industry for Sustainable Development, ACI Concrete International, Vol. 24, No. 7, Pp. 23-28.

[11] ACI Committee 363 (1998), State-Of-Art Report on High-Strength Concrete. In: Manual of Concrete Practice ACI, 55 Pp.

[12] M. M. Regourd. (1993) Microstructure of HPC Ch 2 – in High Performance Concrete from Material to Structure, Malier Yves (Ed.), E&FN SPON, P3.

[13] S. Wild, J.M. Khatib and A. Jones. (1996), Relative Strength, Pozzolanic Activity and Cement Hydration in Superplasticised Metakaolin Concrete. Cem. Concr. Res. 26 10, Pp. 1537–1544.

[14] Cook, D. J. And Suwanvitaya, P. (1981), Rice Husk Ash Based Cements-A State-Of-The-Art Review, Proc. ESCAP/RCTT *Workshop On Rice Husk Ash Cement, New Delhi.*

[15] Rick Stritter, P.E. (2004), EWB – USA Structural Guideline.

[16] ACI SP-19 (1988), In: Cement and Concrete Terminology 107, American Concrete Institute, Detroit.

[17] Mehta, P. K. (1992), Rice Husk Ash-A Unique Supplementary Cement Material, Advances In Concrete Technology, Advances In Concrete Technology, Ed. By Malhotra, CANMET, Ottawa, Canada

[18] Gemma R. De Sensale (2006), Strength Development of Concrete with Rice-Husk Ash, Cement & Concrete Composites 28 158-160.

[19] J. Ambroise, S. Maximilien And J. Pera, (1994), Properties Of Metakaolin Blended Cements; *Adv Cement Based Materials* 1 Pp. 161–168.

[20] Ankara (2001*), Studies Of Black Silica Produced Under Varying Conditions*, Phd Thesis, University Of California, Berkeley, 1976 Cited In Bui, D. D, *Rice Husk Ash A Mineral Admixture For High Performance Concrete*, Phd Thesis, Delft University Press.

[21] J.James, M. S. Rao (1986), Silica From Rice Husk Through Thermal Decomposition, Thermochimica Acta 97, Pp 329 -336

[22] Wilfried J. Bartz (1998), Lubricants And The Environment - Tribology International Vol. 31, Nos 1–3, Pp. 35–47.

[23] Roy J. Irwin (1997), National Park Service With Assistance From Colorado State University Student Assistant For Environmental Contaminants Encyclopedia Oil, Used Motor Oil Entry July 1.

[22] Hwang, C. L., And Wu, D. S. (1989), Properties of Cement Paste Containing Rice Husk Ash, ACI SP-114 (Editor: V. M. Malhotra), Pp. 733-765

[23] Mehta, P. K. (1986), Structure, Properties, and Materials, Englewood Cliffs, NJ: Prentice-Hall.

[24] Mehta, P. K. (1983), Pozzolanic And Cementatious By-Products As Mineral Admixtures For Concrete-A Critical Review, ACI SP-79, Detroit, MI Pp. 1-46.

[25] T.R. Naik, S.S. Singh And M.M. Hossain, (1995), Properties Of High Performance Concrete Systems Incorporating Large Amounts Of High-Lime Fly Ash, *Construct Build Materials* (4), pp. 195–204.

[26] M.N. Haque And O. Kayali, (1998), Properties Of High-Strength Concrete Using A Fine Fly Ash, *Cement Concrete Res* (10), pp. 1445–1452.

[27] M.J. Shannag, (2000), High Strength Concrete Containing Natural Pozzolan and Silica Fume, *Cement Concrete Comps* Pp. 399–406.

[28] American Concrete Institute (1993), ACI 211.4R – Guide for Selecting Proportion for High-Strength Concrete with Portland cement And Fly Ash.

[29] ASTM C 125 (2007), Standard Terminology Relating To Concrete And Concrete Aggregates, ASTM International.

[30] Verbeck, G. J. (1968), Field and laboratory studies of the sulfate resistance of concrete. In Performance of concrete resistance of concrete to sulfate and other environmental conditions: Thorvaldson symposium, 113-24. Toronto: University of Toronto Press.

[31] N. Bouzoubaâ, B. Fournier (1981), Concrete Incorporating Rice Husk Ash: Compressive Strength and Chloride-Ion Durability, Report MTL 2001-5(TR), CANMET, pp 17.

[32] Chopra (1979), Utilisation Of Rice Husk For Making Cement And Cement-Like Binders. In Proc. UNIDO/ESCAP/RCTT Workshop on Rice Husk Ash Cement, Peshawar, Pakistan, pp. 135-149

[33] Mehta, P.K. (1993), Concrete technology at the crossroad – problems and opportunities, Proceedings of V. Mohan Malhotra Symposium – Concrete Technology: Past, Present, and Future, ACI Publication SP-144, USA, pp. 1-30.

[34] ASTM C 496/C 496M (2004), Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens, ASTM international.

[35] Paul Klieger, Joseph F. Lamond (1994), Significance of Tests and Properties of Concrete and Concrete-making Technology & Engineering, pp.130.

[36] Arthur H. Nilson, David Darwin, Charles W. Dolan (2003), Design of Concrete Structures Technology & Engineering, pp. 44.

APPENDICES

Center for By-Products Utilization

SUSTAINABILITY OF CEMENT AND CONCRETE INDUSTRIES

By Tarun R. Naik

CBU-2004-15
REP- 562
January 2005

Presented and Published at the Global Construction: Ultimate Concrete Opportunities, July 2005, Dundee, Scotland.

Department of Civil Engineering and Mechanics
College of Engineering and Applied Science THE
UNIVERSITY OF WISCONSIN – MILWAUKEE

Sustainability of The Cement and Concrete Industries

By

Tarun. R. Naik
Professor of Structural Engineering and Academic Program Director
UWM Center for By-Products Utilization
Department of Civil Engineering and Mechanics
University of Wisconsin - Milwaukee
P.O. Box 784, Milwaukee, WI 53201-0784

ABSTRACT: Sustainability is important to the well-being of our planet, continued growth, and human development. Concrete is one of the most widely used construction materials in the world. However, the production of Portland cement, an essential constituent of concrete, leads to the release of significant amount of CO_2, a greenhouse gas (GHG). The production of one tonne of Portland cement produces about one tonne of CO_2 and other GHGs. The environmental issues associated with GHGs, in addition to natural resources issues, will play a leading role in the sustainable development of the cement and concrete industry during this century. For example, as the supply of limestone decreases it will become more difficult to produce adequate amounts of Portland cement for construction. Once there is no more limestone, and thus no Portland cement, all of the employment associated with the concrete industry as well as new construction projects will be terminated. Therefore, it is necessary to look for sustainable solutions for future concrete construction. A sustainable concrete structure is constructed in order to insure that the total environmental impact during its life cycle, including during its use, will be minimal [1]. Sustainable concrete should have a very low inherent energy requirement, be produced with little waste, be made from some of the most plentiful resources on earth, produce durable structures, have a very high thermal mass, and be made with recycled materials [2]. Sustainable constructions have a small impact on the environment. They use "green" materials, which have low energy costs, high durability, low maintenance requirements, and contain a large proportion of recycled or recyclable materials. Green materials also use less energy, resources, and can lead to high-performance cements and concrete. Concrete must keep evolving to satisfy the increasing demands of all of its users. Designing for sustainability means accounting for the short-term and long-term environmental consequences in the design.

Keywords: By-products, Environment, Portland cement, Pozzolan, Sustainable concrete.

Biography: Tarun R. Naik, FACI, FASCE, is a Professor of Structural Engineering and Academic Program Director of the UWM Center for By-Products Utilization (UWM-CBU) at the University of Wisconsin-Milwaukee. He is a member of ACI Committees 123, Research; 229, Controlled Low-Strength Materials (CLSM); 232, Fly Ash and Natural Pozzolans in Concrete; 555, Concrete with Recycled Materials; and a member of the ACI Board Advisory Committee on Sustainable Developments. He was also Chairman of the ASCE Technical Committee on Emerging Materials (1995-2000).

INTRODUCTION

According to the World Commission on Environment and Development sustainability means "Meeting the needs of the present without compromising the ability of the future generations to meet their own needs" [illegible] The sustainability of the cement and concrete industries is imperative to the well-being of our planet and to human development. However, the production of Portland cement, an essential constituent of concrete, leads to the release of a significant amount of CO_2 and other greenhouse gas (GHGs). The production of one ton of Portland cement produces about one ton of GHGs [4]. The environmental issues associated with CO_2 will play a leading role in the sustainable development of the cement and concrete industry during this century. One of the biggest threats to the sustainability of the cement industry is the dwindling amount of limestone in some geographical regions. Limestone is essential to the production of Portland cement. As limestone becomes a limited resource, employment and construction associated with the concrete industry will decline. Therefore, those involved with these industries must develop new techniques for creating concrete with minimal use of limestone. Concrete production is not only a valuable source of societal development, but also a significant source of employment. Concrete is the world's most consumed man-made material. It is no wonder that in the U.S.A. alone, concrete construction accounted for 2,000,000 jobs in 2002 [5]. Moreover, concrete is second only to water consumption in all materials consumed worldwide. About 3.5 billion cu. yd. of concrete was produced in 2002 worldwide. This equals to more than ½ cu. yd. of concrete produced per person worldwide. Therefore, to create not only sustainable societal development, but also to sustain employment, such as batch plant operators, truck drivers, ironworkers, laborers, carpenters, finishers, equipment operators, and testing technicians, as well as professional engineers, architects, surveyors, and inspectors, the concrete industry must continue to evolve with the changing needs and expectations of the world.

WHAT IS SUSTAINABILITY?

Limestone is used to manufacture Portland cement. Currently, Portland cement is the most commonly used material (Figure 1).

Entire geographical regions are running out of limestone resource to produce cement. And major metropolitan areas are running out of materials to use as aggregates for making concrete. Sustainability requires those in the construction industry to take the entire life-cycle, including construction, maintenance, demolition, and recycling of buildings into consideration [2, 6].

A sustainable concrete structure is one that is constructed such that the total societal impact during its entire life cycle is minimal. Designing with sustainability in mind includes accounting for the short-term and long-term consequences of the structure. In order to decrease the long-term impact of structures, the creation of durable structures is paramount.

Building in a sustainable manner and scheduling appropriate building maintenance are significant in the "new construction ideology" of this millennium. In particular, to build in a sustainable manner means to focus attention on the effects on human health, energy conservation, and physical, environmental & technological resources for new and existing buildings. It is also important to take into account the impact of construction technologies and methods when creating sustainable structures [2]. An integrated sustainable design process can reduce the project costs and operating costs of the development.

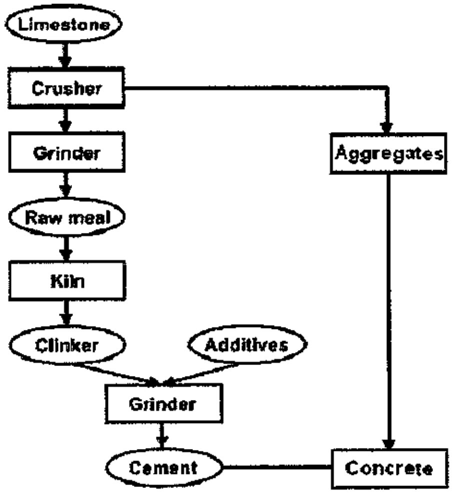

Figure 1 Limestone for Cement and Concrete (modified from [6]).

The production of one ton of Portland cement releases approximately one ton of CO_2 & other greenhouse gases (GHGs) into the atmosphere [4].

There are many challenges associated with Portland cement production. Of these, energy and resource conservation, the cost of producing Portland cement, and GHG emissions are the most significant. Therefore, supplementary cementing materials such as fly ash and slag should replace larger amounts of Portland cement in concrete. However, before any construction occurs, all aspects of the building materials to be used should be evaluated. In order to build structures and infrastructure that is cost efficient, environmentally friendly, and durable, the impact of the building materials on local and worldwide air conditions must be examined [2]. CO_2 emissions are expected to rise by about 50 % by 2020 from the current levels due to Portland cement production (Table 1).

Table 1 CO_2 Emissions in 2002; Total CO_2 emissions worldwide – 21 billion tons [4].

COUNTRY	PERCENT, CO_2
U.S.A.	25
E.U.	20
Russia	17
Japan	8
China	>15
India	>10

For each ton of Portland cement clinker, 1.5 to 10 kg of NOx is released into the atmosphere. In 2000, worldwide cement clinker production was approximately 1.5 billion tons. That means that in 2000 between 23 and 136 billion kg of NOx was produced to make Portland cement clinker [4].

If the challenges associated with reducing CO_2, NOx, and other GHGs are to be met, then the concrete industry must develop other materials to replace Portland cement. Use of blended cements and chemical admixtures must be significantly increased for sustainability of the cement and concrete industries.

CONCRETE

For over 200 years, concrete has been accepted for its long-lasting and dependable nature. In addition to durability and dependability, concrete also has superior energy performance, is flexible in design, affordable, and is relatively environmentally friendly [7]. It can be expected that concrete will be needed to both increase industrialization and urbanization while protecting the environment. To do this, the concrete industry should consider recycling industrial by-products such as fly ash safely and economically. When industrial by-products replace cement, even up to 70 %, in concrete, the environmental impact improves along with the energy efficiency, and durability of concrete [8].

Concrete is a building material that is not only strong and durable, but can also be produced in ways that are environmentally friendly, and architecturally moldable in esthetically pleasing forms [9]. With sustainable concrete structures and infrastructure, the concrete industry can develop a sustainable future for generations yet to come. Furthermore, buildings that are constructed to be both durable and environmentally safe often lead to higher productivity because the buildings generally lead to better air quality and, therefore, higher productivity [10]. One example of the advantages of sustainable concrete is buildings constructed with concrete that have reduced maintenance and energy costs. Another is concrete highways, which reduce the fuel needed for heavily loaded trucks. A third example of the benefits of sustainable concrete construction is illustrated in insulating concrete homes, that have energy reductions of up to 40 % [7].

The cement and concrete industries can make substantial contributions to sustainable developments by creating and adopting technologies that can reduce the emissions of greenhouse gases. The cement and concrete industries could contribute to meeting the goals and objectives of the 1997 Kyoto Protocol [illegible] Those involved with the manufacture of Portland cement would have a huge impact on the sustainable development of the concrete industry as a whole.

There are a number of characteristics that apply to innovative concrete products. First, they are produced with precast or cast-in-place reinforced concrete elements that are made with Portland cement and pozzolanic materials that includes renewable and/or recycled components. Second, innovative concrete products are constructed to enhance the performance of concrete elements, which may also contain recycled concrete as aggregates. High performance materials are intended to reduce cross-sections and the volume of concrete produced. They are also intended to increase the durability of concrete structures to minimize the maintenance needs of the concrete construction, and limit the amount of non-renewable special repair materials that need to be used in the maintenance of the concrete [10].

Concrete producers are creating sustainable solutions for many market sectors including agriculture and construction. In agriculture, integrated waste management solutions have been developed that convert manure into biogas, nutrient rich fertilizer, and reusable water. In construction, industrial, commercial, and institutional buildings are being constructed so that they are more energy efficient, have better air quality, and necessitate less maintenance [illegible]

U.S. foundries generate over 7 million tonnes (8 million tons) of by-products. Wisconsin alone produces nearly 1.1 million tonnes (1.25 million tons) of foundry by-products, including foundry sand and slag. Most of these by-products are landfilled. Landfilling is not a desirable option because it not only causes a huge financial burden to foundries, but also makes them liable for future environmental costs, liability, and restrictions associated with landfilling [11]. In addition, in 1996 the USA produced 136 million tons of construction and demolition (C & D) debris; about 1.5 kg per person per day. About 25 to 40% of landfill space is C&D debris [12]. If this trend continues, the cost of landfilling will continuously increase, as will the potential health and environmental risks of landfill materials. Furthermore, the cost of landfilling is escalating due to shrinking landfill space and stricter environmental regulations. One of the innovative solutions appears to be high-volume uses of foundry by-products in construction materials [11].

A study was reported in 1999 whose aim was to evaluate the environmental impact of Controlled Low Strength Materials (CLSM) incorporating industrial by-products such as coal fly ash and used foundry sand [11]. The results demonstrated that excavatable flowable slurry incorporating fly ash and foundry sand as a replacement of fly ash up to 85% could be produced. In general, inclusion of both clean and used foundry sand caused a reduction in the concentration of certain contaminants. The use of foundry sand in flowable CLSM slurry, therefore, provided a favorable environmental performance.

PORTLAND CEMENT

Portland cement is not an environmentally friendly material; its manufacture creates greenhouse gas emissions; and, it also reduces the supply of limestone. As good engineers, we must reduce the use of Portland cement in concrete. We must use more blended cements.

The most energy intensive stage of the Portland cement production is during clinker production. It accounts for all but about 10 % of the energy use and nearly all of the GHGs produced by cement production. Kiln systems evaporate inherent water from the raw meal and calcine the carbonate constituents during clinker preprocessing [6].

Sources of CO_2 and GHG emissions in the manufacturing of Portland cement [4] are:

- from calcinations of limestone = ± 50 –55%;
- from fuel combustion = ± 40 –50%; and,
- from use of electric power = ± 0 –10%.

INNOVATIVE CEMENT PRODUCTS

While the embodied energy linked to concrete is low, supplementary cementing materials (SCM), especially fly ash, have been used by the concrete industry for over 70 years. Their use can contribute to a further reduction of concrete's embodied energy. When used wisely and judiciously, SCM can improve the long-term properties of concrete. Fly ash can, and does, regularly replace Portland cement in concrete [4, 8, 13].

One process that is even more environmentally friendly and productive is blended cements. Blended cements have been used for many decades and are made when various amounts of clinker are blended and/or interground with one or more additives including fly ash, natural pozzolans, slag, silica fume and other SCM. Blended cements allow for a reduction in the energy used and also reduces GHGs emissions [4, 13].

Most innovative concrete mixtures make use of SCMs to partially replace cement. The advantages of using of blended cements include increased production capacity, reduced GHG emissions, reduced fuel consumption in the final cement productivity, and recycling of SCMs [6, 7].

The manufacture of Portland cement is the third most energy intensive process, after aluminum and steel. In fact, for each ton of Portland cement, about six million BTU of energy is needed [4, 11].

Although cement production is energy inefficient, there have been major initiatives that have reduced energy consumption [6]. Of these, the most significant has been the replacement of wet production facilities with dry processing plants. In addition the cement industry has also moved away from petroleum-based fuel use.

Despite these advances, there are still some shortcomings when energy use is evaluated for the concrete industry. Dry process cement plants use pre-heaters, which increase the alkali content of cement [6]. Thus, researchers need to continue to develop ways to control the alkali content without increasing the energy consumption levels of the cement [10]. Furthermore, current innovations and energy savings are linked to the actual amount of energy consumption by wet-to-dry-kiln conversions and the number of pre-heaters needed to complete the process [6].

For each million ton of capacity, a new Portland cement plant costs over 200 million dollars. The cost associated with the production of Portland cement, along with the CO_2 emissions and energy issues make it unlikely that developing countries will be able to employ such technology. Also, government regulations of GHGs will likely force the cement industry to create blended cements and use supplementary materials for blended cements in order to meet the societal development needs [4, 6].

To produce one ton of Portland cement, 1.6 tons of raw materials are needed. These materials include good quality limestone and clay. Therefore, to manufacture 1.6 billion tons of cement annually, at least 2.5 billion tons of raw materials are needed [14].

As good engineers, we must use environmentally friendly materials to replace a major part of portland cement for use in the concrete. In the USA these materials primarily are fly ash, slag, silica fume, natural pozzolans, rice-husk ash, wood ash, and agricultural products ash. These all can be used to supplement the use of cement in concrete mixtures while improving product durability.

One of the important benefits of the increased use of other cementitious materials is the reduction of GHG emissions. With a replacement of cement with other recyclable resources, up to 15% of worldwide CO_2 emissions would be reduced. A replacement of 50% of cement worldwide by other cementitious materials would reduce CO_2 emissions by 800 million tons. This is equivalent to removing approximately 1/4 of all automobiles in the world [4].

Fly ash availability in 2002 is estimated at 100 million tons; and, in 2010 it is 160 million tons. While Portland cement availability in 2002 is estimated at 80 million tons; and, in 2010 it is 100 million tons. The fly ash disposal challenge, and the limited availability of Portland cement have the same solution: replace large amounts of Portland cement with fly ash to create durable and sustainable concrete.

THE HANNOVER PRINCIPLES FOR DESIGN FOR SUSTAINABILITY

In 1991, as the planning of the World's Fair was underway, the City of Hannover, Germany asked William McDonough and Michael Braungart to create sustainability principles to guide the large-scale development of EXPO 2000 in Hannover. "The Hannover Principles - Design for Sustainability" also include directives concerning the use of water. Although these guidelines were created for the World Fair, they are still a good tool to guide current and future development around the world [2].

Designers, planners, government officials, and all those who participate in the construction of new buildings and infrastructure should use the Hannover Principles. A new design philosophy has developed from these principles and should be included in the proposed sustainable systems and construction in the future. There are a number of examples of societies that have created sustainable and environmentally friendly communities. There is hope that the Hannover Principles will inspire development and improvements that are committed to sustainable growth with practical limits to create a sustainable and supportive future for communities and the world.

Hannover Principles by William McDonough [2]: insist on rights of humanity and nature to co-exist; recognize interdependence; respect relationships between spirit and matter; accept responsibility for consequences of design; create safe objects of long-term value; eliminate the concept of waste; rely on natural energy flows; understand the limitations of design; and, seek constant improvement by the sharing of knowledge.

The Hannover Principles are not “cast-in-concrete”. They were devised to provide a tangible document that could evolve and be adapted as our understanding of our interdependence with nature becomes more important over time.

For sustainability consider your actions on [2]: materials (use indigenous materials); land use (protect and create rich soil); urban context (preserve open spaces); water (use rainwater and gray-water); wastes (recycle), air (create clean air); energy (use solar & wind energy; recycle waste energy); and, your responsibility to nature (create silence), and, for the future generations minimize or eliminate maintenance.

Materials are key to creating sustainable and responsible concrete designs. In order to ensure that the most effective and environmentally friendly materials are being used, the entire life-cycle of the structure should be taken into consideration. Material choice should include anticipation of the extraction, processing, transport, construction, operation, disposal, re-use, recycling, off-gassing and Volatile Organic Compounds (VOC) associated with the material

[2]. According to McDonough, constructions should be flexible to allow and serve different needs (e. g., today's storage building can be tomorrow's school). Adapt materials that are sustainable in their process of extraction, manufacture, transformation, and degradation, as well as recyclability. Consider toxicity, off-gassing, finish, and maintenance. Recycling is essential. Make allowance for disassembly and reuse. Plan for reuse of the entire structure in the future. Minimize use of hazardous chemicals. Eliminate waste that cannot be part of naturally sustainable cycle. Any solid wastes remaining must be dealt with in a non-toxic manner. Life-cycle costs must be analyzed. Life-cycle cost analysis is a process to evaluate energy use and environmental impact during the life of the product, process, and/or activity. This process must include extraction and processing of raw materials, manufacturing, transportation, maintenance, recycling, and returning to the environment. Evaluate and understand costs and benefits in both the short-term and long-term. Use recycled concrete for aggregates.

For the sustainability of the cement and concrete industries use less water and portland cement in concrete production; and, use more blended cements and tailor-made chemical admixtures.

The devastation of air is a global problem, regardless of the locality in which the pollution is created [2]. The overall design of concrete structures must not contribute to atmospheric degradation. Those involved in the cement and concrete industries must evaluate ozone depletion and global warming throughout the construction and planning process. A major contribution to this effort will be the use of more blended Portland cement to minimize global warming.

Water resources are being depleted by various uses [15]. Therefore, potable water should be conserved to serve life-sustaining needs rather than infrastructural needs. Rainwater and surface run-off water can be used as a water conservation method by recycling these water resources in construction instead of using potable water. Gray water should be recycled and used for grass, shrubs, plants, trees, and gardens; as well as for concrete production [2]. Furthermore, mixtures with less water should be developed with new technologies to create mortar and concrete containing a minimal amount of water.

Benjamin Franklin said, over 200 years ago in Poor Richard's Almanac "When the well's dry, we know the worth of water," [16]. Many facilities may have requirements that can be completed with non-potable water. By using non-potable water, a significant amount of money can be saved by avoiding or reducing potable water purchases and sewerage costs. To be as effective as possible, non-potable water construction and building uses should be identified early to be the most cost-effective. Four ways to utilize and recycle water are to reuse water on site for repeated cycles of the same task, treat and reuse water on site for multiple purposes, use gray water (shower, sink, bath and laundry excess) water after solids have been eliminated, and collect non-potable water from sources such as rainwater, lakes, rivers and ponds for use in construction [15].

Energy efficiency, providing the same (or more) services for less energy, helps to protect the environment. When less energy is used, less energy is generated by power plants, thus reducing energy consumption and production. This in turn reduces GHGs and improves the quality of the air. Energy efficiency also helps the economy by saving costs for consumer and businesses. According to Mc Donough [2]: Use buildings' thermal inertia (e. g., concrete building's mass allows it to retain heat). Use day lighting and natural ventilation. Use wind power and solar power. Recycle waste energy. Judiciously use color materials on surfaces. Reduce heat-islands in buildings. Manage and moderate micro-climates of buildings.

WASTE MATERIALS

Contractors should reuse industrial by-products and post-consumer wastes in concrete. Post-consumer wastes that should be considered for use in concrete include glass, plastics, tires, and aluminum, steel & tin cans. To do this successfully, contractors must watch for harmful hydration reactions and changes in volume. The recycling of industrial by-products has been well established in the cement and concrete industries over the past decades [16]. The use of coal fly ash in concrete began in the 1930s, but volcanic ash has been reused for mortar and concrete for several millenniums in Egypt, Italy, Mexico, and India. The use of by-products such as rice-husk ash, wood ash, silica fume and other pozzolanic materials, in addition to coal fly ash, can help to reduce the need for Portland cement in addition to creating more durable concrete and reducing greenhouse gas emissions [4, 13, 17]. This will also contribute to the improvement of air quality, reduction of solid wastes, and sustainability of the cement and concrete industry [13].

In summary, for sustainability of the cement and concrete industries: use less Portland cement; use less water; use applications-specific high-quality, durable aggregates; and, use chemical admixtures.

Fundamental laws of nature state that we cannot create or destroy matter; we can only affect how it is organized, transformed, and used. Obey the rules of nature: use only what you need and never use a resource faster than nature can replenish it.

Resources are extracted from the earth by 20% more than the earth produces. Therefore, what is consumed in 12 months will take 14.4 months to be replenished. The use of sustainable development procedures will reduce that rate [18]. "The issue is not environment vs. development or ecology vs. economy; the two can be (and must be) integrated [19].

CONCLUSIONS

As Kofi Annan, U.N. Secretary General said in 2002, "We have the human and material resources needed to achieve sustainable developments, not as an abstract concept but as concrete reality" [18]. Professionals involved in the cement and concrete industries have the responsibility to generate lasting innovations to protect both the industries' future viability and the health of our environment. Large volumes of by-product materials are generally disposed in landfills. Due to stricter environmental regulations, the disposal costs for by-products are rapidly escalating. Recycling and creating sustainable construction designs not only contributes to reduced disposal costs, but also aids in the conservation of natural resources. This conservation provides technical and economic benefits. It is necessary for those involved in the cement and concrete industries to eliminate waste and take responsibility for the life cycle of their creations. In order to be responsible engineers we must all think about the ecology, equity, and economy of our design [2].

We must apply forethought into direct and meaningful action throughout our development practices. Sustainable designs must be used as an alternative and better approach to traditional designs. The impacts of every design choice on the natural and cultural resources of the local, regional, and global environments must be recognized in the new design approaches developed and utilized by the cement and concrete industries.

REFERENCES

1. Concrete for the Environment. Published on Behalf of the Nordic Network Concrete for Environment by SP Swedish National Testing and Research Institute, Boras, Sweden, June 2003, 8 pages.

2. McDONOUGH, W Partners. The Hannover Principles: Design for Sustainability, EXPO 2000, The World's Fair, Hannover, Germany, 1992.

3. UNFCCC COP9 Report, Delivering the Kyoto Baby, REFOCUS, International Renewable Energy Magazine, Kidlington, Oxford, UK, Jan/Feb. 2004, pp. 52-53.

4. MALHOTRA, V M. Role of Supplementary Cementing Materials and Superplasticizers in Reducing Greenhouse Gas Emissions, Proceedings of ICFRC International Conference on Fiber Composites, High-Performance Concrete, and Smart Materials, Chennai, India, January 2004, pp. 489-499.

5. United States House Resolution 394, March 2004.

6. WORRELL, E, AND GALTISKY, C. Energy Efficiency Improvement and Cost Saving Opportunities for Cement Making, Lawrence Berkeley National Laboratory, Publication No. LBNL-54036, January 2004, 62 pages.

7. "Concrete Thinking for a Sustainable Future." Cement Association of Canada, http://www.cement.ca/cement.nsf/internetE/28BAAE6AB42AB69C852567B60056B657?opendocument, May 2004.

8. NAIK, T R, KRAUS, R N, RAMME, B W, AND SIDDQUE, R. Long-Term Performance of High-Volume Fly Ash Concrete Pavements, ACI Materials Journal, Vol. 100, No. 2, 2003, pp. 150-155.

9. Liquid Stone: New Architecture in Concrete, National Building Museum, Washington, D.C., 2004.

10. COPPOLA, L, CERULLI, T, AND SALVIONI, D. Sustainable Development and Durability of Self-Compacting Concretes, Eighth CANMET/ACI International Conference on Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Las Vegas, NV, 2004, pp. 29–50.

11. NAIK, T R, AND KRAUS, R N. The Role of Flowable Slurry in Sustainable Developments in Civil Engineering, Proceedings of the ASCE Conference on Materials and Construction - Exploring the Connection, Cincinnati, Ohio, 1999, 9 pages.

12. McKAY, D T. Sustainability in the Corps of Engineers, a paper presented at the Technical Session Sponsored by the ACI Board Advisory Committee on Sustainable Developments, Washington, D. C., March 2004.

13. MEHTA, P K. Greening of the Concrete Industry for Sustainable Development, ACI Concrete International, Vol. 24, No. 7, 2002, pp. 23-28.

14. WU, Z. Development of High-Performance Blended Cement, PhD thesis, T. R. Naik advisor, Department of Civil Engineering and Mechanics, College of Engineering and Applied Science, 2000, 177 pages.

15. BOURG, J. Water Conservation, http://www.wbdg.org/design/resource.php?cn=0&cx=0&rp=50, April 27, 2004.

16. http://www.cbu.uwm.edu, June 30, 2004.

17. White Paper from the ACI Board Advisory Committee on Sustainable Development, Feb. 2004.

18. TIME Magazine, August 26, 2002, pp. A8.

19. Sustainable Developments: Planning for our Future, by Ricoh Company, Ltd., TIME Magazine, March 2004.

ELSEVIER

Available online at www.sciencedirect.com
SCIENCE DIRECT•

Cement & Concrete Composites 28 (2006) 158–160

Cement & Concrete Composites
www.elsevier.com/locate/cemconcomp

Strength development of concrete with rice-husk ash

Gemma Rodríguez de Sensale

Facultad de Ingeniería, Julio Herrera y Reissig 565, CP 11300 Montevideo, Uruguay

Received 21 April 2005; accepted 21 September 2005
Available online 10 November 2005

Abstract

This paper presents a study on the development of compressive strength up to 91 days of concretes with rice-husk ash (RHA), in which residual RHA from a rice paddy milling industry in Uruguay and RHA produced by controlled incineration from the USA were used for comparison. Two different replacement percentages of cement by RHA, 10% and 20%, and three different water/cementicious material ratios (0.50, 0.40 and 0.32), were used. The results are compared with those of the concrete without RHA, with splitting tensile strength and air permeability. It is concluded that residual RHA provides a positive effect on the compressive strength at early ages, but the long term behavior of the concretes with RHA produced by controlled incineration was more significant. Results of splitting tensile and air permeability reveal the significance of the filler and pozzolanic effect for the concretes with residual RHA and RHA produced by controlled incineration.

Keywords: Rice-husk ash; Pozzolans; Strength; High-strength concrete

1. Introduction

In Uruguay, rice production has had a dramatic increase over the past 10 years, becoming the most important crop since 2001; the main use of rice husk is as fuel in the rice paddy milling process. The use of this fuel generates a huge volume of ash. The rice-husk ash (RHA) has no useful application, is usually dumped into water streams and causes pollution and contamination of springs. As a result, the use of rice-husk ash has aroused great interest in Uruguay.

Rice-husk ash is a mineral admixture for concrete [1,2]; the behavior of cementitious products varies with the source of RHA [3,4]. The basic aim of this study is to investigate the influence of residual RHA from the rice paddy milling industry in Uruguay and RHA produced by controlled incineration from the United States, used for comparison, on strength development of concretes at different ages.

2. Experimental program

The following materials were used in the preparation of the concrete specimens: fine aggregate (local natural sand) with maximum aggregate size of 4.75 mm; coarse aggregate (crushed granite) with maximum aggregate size of 12.5 mm; Portland Cement type I (normal portland cement); and superplasticizer based on a sulfonated naphthalene formaldehyde condensate. Two sources of ash were considered; a residual RHA from the unique rice paddy milling industry in Uruguay (UY RHA) and a homogeneous ash produced by controlled incineration from the United States (USA RHA), for comparison.

The residual RHA used for this work was a processed waste dry-milled for the necessary time to obtain a median particle size of 8 μm, a defined specific surface by nitrogen adsorption [5], and with the maximum activity index according to the ASTM C311-98b. This procedure of optimization is presented in [6]. Table 1 shows the chemical composition, physical properties and activity index of the cementitious materials.

Table 1
Physical properties and chemical analyses of the cement and RHA used

	Cement	RHA	
		UY	USA
Physical tests			
Specific gravity	3.14	2.06	2.16
Fineness			
Specific surface, Blaine, m^2/kg	309	–	–
Nitrogen adsorption, m^2/kg	–	28,800	24,300
Setting time, min			
Initial	145	–	–
Final	275	–	–
Compressive strength, Mpa			
1-day	10.1	–	–
3-day	22.8	–	–
7-day	33.1		–
28-day	45.1		–
Chemical Analyses, %			
Silicon dioxide (SiO_2)	21.98	87.2	88
Aluminium oxide (Al_2O_3)	4.65	0.15	–
Ferric oxide (Fe_2O_3)	2.27	0.16	0.1
Calcium oxide (CaO)	61.55	0.55	0.8
Magnesium oxide (MgO)	4.27	0.35	0.2
Manganese oxide (MnO)	–	–	0.2
Sodium oxide (Na_2O)	0.11	1.12	0.7
Potassium oxide (K_2O)	1.04	3.60	2.2
Sulphur oxide (SO_3)	2.19	0.32	–
Loss on ignition	2.30	6.55	8.1
Compounds			
Tricalcium silicate C_3S	44.0	–	–
Dicalcium silicate C_2S	29.9	–	–
Tricalcium aluminate C_3A	8.5	–	–
Tetracalcium aluminoferrite C_4AF	6.9	–	–
Activity index			
ASTM C311-98b	100	92.93	92.4

Chemical analysis indicate that the two ashes are mainly composed of SiO_2. The median particle size of the two ashes is the same, and the activity index are similar. X-ray diffraction analysis indicated that the USA RHA can be considered to be non-crystalline RHA; but the UY RHA showed crystalline materials, which were identified as cristobalite. A rapid analytical method to evaluate amorphous silica in the rice husk ashes according to [7] has been used; the percentage of reactive silica contained in the USA RHA was 98.5% and in the UY RHA was 39.55%.

A total of 15 concrete mixes were made; for each RHA, six concrete mixes were made, and three concretes without RHA for comparison. The different mix proportions by mass of the materials used are given in Table 2. The replacement of cement by RHA was made by volume, because the RHA presents less specific gravity than the cement Portland, and the paste content in volume was kept the same (35% cement paste content) for the different mix proportions. The values of the slump test are also indicated in Table 2, where superplasticizer percentages are used in relation to weight of cementitious materials. Superplasticizer was used in very low percentages according to the results obtained in the slumps, to allow consistency adjustments (slump = 60 ± 20 mm) without changing the proportion of the other materials.

Cylindrical concrete test specimens were cast. They were compacted by external vibration and kept protected after casting to avoid water evaporation. After 24 h they were demolded and stored in a moist room until the testing date.

100 × 200-mm cylinders were used to observe the compressive strength at 7, 28 and 91 days. In order to obtain more information about the development of strength of the concretes, splitting tensile tests and air permeability on cylinders of 100 × 200 mm and 150 × 300 mm respectively, with lower and higher water/cementitious materials ratios at the age of 28 days, were analysed. Air-permeability for concrete was determined with the "Torrent permeability tester" method [8,9]. The particular features of the Torrent method are a two-chamber vacuum cell and a pressure regulator, which ensures that air flows at right angles to the surface and is directed towards the inner chamber; this allows the calculation of the permeability coefficient K_t on the basis of a simple theoretical model. By comparing the results [9] of gas permeability measured by the Torrent permeability tester (K_t) and oxygen permeability obtained for the Cembureau method (K_O), the following relation is presented: $K_O = 2.5\ K_t^{0.7}$ where K_O and K_t are expressed in $10^{-16}\ m^2$.

3. Results and discussion

Table 3 shows the test results (strength and permeability). Each value represents the average of five experimental observations. At lower ages (7 days), concretes with UY

Table 2
Mix proportions of concrete

W/(c + RHA)	RHA (%)	Cement (kg/m^3)	Fine Agg. (kg/m^3)	Coarse Agg. (kg/m^3)	Superplast (%)		Slump (mm)	
					UY	USA	UY	USA
0.32	0	534	690	1050	0.40		47	
	10	481	690	1050	0.20	0.70	45	56
	20	427	690	1050	0.20	0.80	48	63
0.40	0	462	723	1018	0.10		40	
	10	416	723	1018	0.20	0.27	40	56
	20	370	723	1018	0.40	0.50	53	65
0.50	0	408	758	983	–		61	
	10	367	758	983	–	0.30	94	79
	20	327	758	983	–	0.40	67	53

E-mail address: gemma@fing.edu.uy

0958-9465/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.cemconcomp.2005.09.005

Table 3
Test results

w/(c + RHA)	RHA		f_c (MPa)			$f_{t,d}$ (MPa) 28d	K_t (m^2) 28d
	Type	%	7d	28d	91d		
0.32		0	48.4	55.5	60.6	3.63	1.08×10^{-16}
	UY	10	51.1	60.4	64.3	3.57	0.23×10^{-16}
		20	44.3	54.8	62.7	3.34	0.05×10^{-16}
	USA	10	39.5	51.4	64.5	3.62	0.08×10^{-16}
		20	30.5	47.4	68.5	3.54	0.03×10^{-16}
0.40		0	35.8	42.3	45.6		
	UY	10	41.1	50.4	54.9		
		20	27.9	40.7	51.4		
	USA	10	29.7	40.8	51.5		
		20	23.6	39.4	57.3		
0.50		0	24.6	32.9	35.9	2.85	28.20×10^{-16}
	UY	10	24.1	31.5	35.5	2.32	71.82×10^{-16}
		20	24.9	34.9	37.9	2.63	49.10×10^{-16}
	USA	10	22.7	34.5	44.4	2.92	26.36×10^{-16}
		20	20.8	35.9	52.9	3.00	14.20×10^{-16}

Keys: f_c = axial compressive strength; $f_{t,d}$ = splitting tensile strength; K_t = permeability coefficient.

RHA present higher compressive strength that concretes with USA RHA. At higher ages (91 days), the RHA concrete had higher compressive strength in comparison with that of concrete without RHA, and the highest values of compressive strengths were achieved in concretes with 20% USA RHA. The long term compressive strength of the concretes with UY RHA is not as high as the one obtained with USA RHA, which also increases as the RHA content rises.

The results of splitting tensile strength and air permeability reveal the significance of the filler and pozzolanic effect for the concretes with RHA. On the one hand, the results are consistent with the compressive strength development at 28 days for the USA RHA. On the other hand, in the concretes with UY RHA, lower splitting tensile strengths and less air permeability are observed, which can be due to the fact that with residual RHA, the filler effect of the smaller particles in the mixture is higher than the pozzolanic effect.

4. Conclusions

The RHA concrete had higher compressive strength at 91 days in comparison with that of the concrete without RHA, although at 7 and 28 days a different behavior was observed between the concretes with the two RHA considered.

The increase in compressive strength of concretes with residual RHA is better justified by the filler effect (physical) than by the pozzolanic effect (chemical/physical). The increase in compressive strength of concretes with RHA produced by controlled incineration is mainly due to the pozzolanic effect.

It is concluded that residual RHA provides a positive effect on the compressive strength of concretes at early ages, but in the long term, the behavior of the concretes with RHA produced by controlled incineration was more significant.

References

[1] RILEM Committee 73-SBC. Final report: siliceous by-products for use in concrete. Mater Struct 1988;21(121):69–80.

[2] Mehta PK. Rice-husk ash—a unique supplementary cementing material. In: Advances in concrete technology. Proc.: CANMET, Ontario, 1992. p. 419–43.

[3] James J, Rao MS. Reactivity of rice husk ash. Cem Concr Res 1986;16:296–302.

[4] Malhotra VM, Mehta PK. Pozzolanic and cementitious materials. Adv Concr Technol, vol. 1. Canada: Gordon and Breach Publ.; 1996.

[5] Mehta PK. Highly durable cement products containing siliceous ashes. USA Patent 5, 346, 548. 13 September 1994.

[6] Rodriguez de Sensale G. Estudio sobre las propiedades mecánicas de hormigones de alta resistencia con materiales disponibles en nuestro medio y la influencia de la incorporación de ceniza de cáscara de arroz. CSIC Report, I + D Project (2002), Montevideo, Uruguay, 2002.

[7] Paya J, Monzo J, Borrachero MV, Mellado A, Ordoñez LM. Determination of amorphous silica in rice husk ash by a analytical method. Cem Concr Res 2001;31(2):227–31.

[8] Torrent R. Gas permeability of high-performance concretes-site and laboratory test. High-performance concrete and performance and quality of concrete structures, Gramado. In: Proceedings second CANMET/ACI Int., 1999. p. 291–308.

[9] Torrent R, Frenzer G. A method for rapid determination of the coefficient of permeability of the covercrete. In: International symposium non-destructive testing in civil engineering. Proceedings (NDT-CE). 1995. p. 985–92.

ELSEVIER

Construction and Building Materials 17 (2003) 311–318

Construction and Building MATERIALS

www.elsevier.com/locate/conbuildmat

Effect of used engine oil on properties of fresh and hardened concrete

Bilal S. Hamad*[1], Ahmad A. Rteil[2], Mutassem El-Fadel[3]

Department of Civil and Environmental Engineering, American University of Beirut, P.O. Box 11-0236, Beirut, Lebanon

Accepted 14 January 2003

Abstract

There is a current trend all over the world to investigate the utilization of processed and unprocessed industrial by-products and domestic wastes as raw materials in cement and concrete. This has a positive environmental impact due to the ever-increasing cost of waste disposal and stricter environmental regulations. Historically, reference books on concrete technology and cement chemistry indicate that the leakage of oil into the cement in older grinding units resulted in concrete with greater resistance to freezing and thawing. This effect is similar to adding an air-entraining chemical admixture to the concrete. Such information is not backed by any research study reported in the literature. The objective of the research reported in this paper was to investigate the effects of used engine oil on properties of fresh and hardened concrete. The main variables included the type and dosage of an air-entraining agent (commercial type, used engine oil, or new engine oil), mixing time, and the water/cement ratio of the concrete. Results showed that used engine oil increased the slump and percentage of entrained air of the fresh concrete mix, and did not adversely affect the strength properties of hardened concrete.

Keywords: Plain concrete; Durability; Freezing and thawing; Oil; Used engine oil; Waste; By-products; Air entrainment

1. Introduction

1.1. By-products and wastes used in concrete

Wastes can be defined as not readily avoidable by-products for which there is no economical demand and for which disposal is required. Processed or unprocessed industrial by-products or wastes can be used as raw materials in cement manufacturing, as components of concrete binder, as aggregates, a portion of aggregate, or ingredients in manufactured aggregates. Some wastes can be used as chemical admixtures and additives, which can alter and enhance selected properties of fresh and hardened concrete. The successful use of industrial by-products or wastes in concrete depends on the required properties of the end product. Economical factors would ultimately determine if potentially beneficial waste could be used as an ingredient in concrete. These factors are generally influenced by the cost of waste disposal, the cost of transportation of waste to a manufacturing site, and existing environmental regulations [1].

Several by-products or wastes have been reported in the literature to be used in concrete:

1. Recycled aggregate concrete is widely used in road construction.
2. Unprocessed wastes have been used as coarse or fine aggregates in concrete with variable success. Such wastes include blast furnace slag aggregate, steel slag aggregate, ferro-chromium and silica-manganese slags, crushed brick, crushed glass, expanded polystyrene granules, cork granules, sawdust, shredded rubber, cane bagasse, wood ash, china clay waste, slate processing waste, and paper waste.
3. Pozzolans such as fly ash, silica fume, granulated blast furnace slag, rice husks ash, and other industrial or natural mineral by-products are used as extenders of Portland cement.
4. Waste-derived fuels such as coke oven gases, pyrolysis gases, landfill gasses, industrial oils, distillation

---

*Corresponding author. Tel.: +961-1-350000; fax: +961-1-744462.

E-mail address: bhamad@aub.edu.lb (B.S. Hamad).

[1] Professor and Chairman.

[2] Graduate Student.

[3] Associate Professor.

0950-0618/03/$ - see front matter © 2003 Elsevier Science Ltd. All rights reserved.
doi:10.1016/S0950-0618(03)00002-3

Table 1
Solutions to the problem of used engine oil as suggested by El-Fadel and Khoury [2]

Method	Advantages	Disadvantages
Re-refining into lube oil	Creates jobs Reduces the amount of imported lubrication oil Environmentally sound long-term solution	Requires well developed waste-oil collection system Recycled lube oil requires a well-developed market Requires extensive capital investment
Re-processing into fuel oil	Same as in re-refining	Same as in re-refining
Destruction	Less capital intensive than the previous solutions Concentrates waste oil disposal to limited sites that can be more easily regulated and controlled	Air emissions May face stiff opposition by local residents and environmental organizations

residues, and halogen-free spend solvents, can be used in manufacturing Portland cement.

5. Many organic fibers, including wastes, are used as concrete reinforcement. These can be classified as natural, which can be either of vegetable or animal origin, or synthetic.

1.2. Used engine oil as a waste

It is estimated that less than 45% of used engine oil is being collected worldwide while the remaining 55% is thrown by the end user in the environment [2]. Used oil affects both marine and human life. Oil in bodies of water raises to the top forming a film that blocks sunlight, thus stopping the photosynthesis and preventing oxygen replenishment leading to the death of the underwater life. In addition, used oil contains some toxic materials that can reach humans through the food chain. Health hazards range from mild symptoms to death. The main source of contaminants in used oil is due to the break down of additives and the interaction of these substances with others found in nature. In this context, the proper management of used oil is essential to eliminate or minimize potential environmental impacts.

El-Fadel and Khoury suggested three solutions to the problem of used oil waste: re-refining the used oil into lube oil, re-processing it into fuel oil, or conduct controlled destruction of the used oil at high temperature [2]. The advantages and disadvantages of each of the three methods are listed in Table 1.

The leakage of oil into the cement in older grinding units has been reported to result in concrete with greater resistance to freezing and thawing [3]. This implies that adding used engine oil to the fresh concrete mix could be similar to adding an air-entraining chemical admixture, thus enhancing some durability properties of concrete while serving as another technique of disposing the oil waste. However, experimental data to support this hypothesis appear to be lacking.

1.3. Advantages and disadvantages of air entrainment

Air entrainment is recommended principally to improve the freeze–thaw resistance of hardened concrete. As the water in moist concrete freezes, it produces osmotic and hydraulic pressures in the capillaries and pores of the cement paste and aggregate. If the pressure exceeds the tensile strength of the paste or aggregate, the cavity will dilate and rupture. The accumulative effect of successive freeze–thaw cycles and disruption of paste and aggregate, eventually cause significant expansion and deterioration of the concrete. Deterioration is visible in the form of cracking, scaling and crumbling. Entrained air voids act as empty chambers in the paste for the freezing and migrating water to enter, thus relieving the pressures described above and preventing damage to the concrete [4].

Deicing chemicals used for ice and snow removal can cause and aggravate surface scaling of concrete pavements. Properly designed and placed air-entrained concrete will withstand deicers for many years. Air-entrained concrete made with a low water/cement ratio and an adequate cement factor with a low tricalcium aluminate cement will be resistant to attack from sulfate soils and waters. Also, the expansive disruption caused by alkali-silica reactivity is reduced through the use of air entrainment. Results of some carbonation tests reported on plain and air-entrained concrete indicate that air entrainment lowers the carbonation, and therefore provides better protection to reinforcing bars against corrosion due to carbonation [5]. Entrained air improves the workability of concrete, reduces segregation and bleeding in freshly mixed and placed concrete, and increases pump-ability of fresh concrete if introduced in low percentages up to 6%.

At constant water/cement ratios, increases in air will proportionally reduce strength. For moderate-strength concrete, each percentile of entrained air reduces the compressive strength approximately 2–6%. Air entrainment also reduces the flexural strength, the splitting

Table 2
Recommended air contents for various exposures, ACI [6]

Nominal maximum size aggregate (inches)[a]	Air content (%)		
	Severe exposure	Moderate exposure	Mild exposure
3/8	7.5	6.0	4.5
1/2	7	5.5	4.0
3/4	6.0	5.0	3.5
1	6.0	4.5	3.0
1.5	5.5	4.5	2.5
2	5.0	4.0	2.0
3	4.5	3.5	1.5

[a] 1 inch=25.4 mm.

tensile strength, and the modulus of elasticity of hardened concrete.

The recommended amount of air to be used in air-entrained concrete depends on many factors such as type of structure, climatic conditions, number of freeze–thaw cycles, extent of exposures to deicers, and extent of exposure to sulfates or other aggressive chemicals in soil or waters. According to the ACI Building Code (ACI 318-02), the recommended amounts of entrained air for different exposures are listed in Table 2 [6].

2. Research significance

The main objective of the research program reported in this paper was to investigate the effect of adding used engine oil to concrete on the properties of fresh and hardened concrete. The significance of the program was to check the hypothesis that adding used engine oil to the fresh concrete mix could be similar to adding an air-entraining chemical admixture, thus enhancing some durability properties of concrete while serving as a technique of disposing the oil waste. Also, it was important to compare the performance of concrete with used engine oil vs. concrete with new engine oil to assess the effect of the type of the oil on concrete properties.

3. Experimental program

Twenty concrete mixes were prepared in two groups (refer to Table 3). The water/cement ratio was 0.62 for the 16 mixes of Group 1, and 0.59 for the 4 mixes of Group 2.

The variables in Group 1 were the type of the air-entraining agent: commercial air-entraining chemical admixture, used engine oil, or new engine oil; the dosage of the air-entraining agent measured as percentage by weight of cement: 0.075, 0.15 or 0.30%; and the mixing time as measured after all ingredients including the air-entraining agent were in the mixer: 2 or 5 min. Based on the results of Group 1, the four mixes of Group 2 were prepared. The variables of Group 2 were the type of the air-entraining agent: used engine oil, or new engine oil; and the dosage of the air-entraining agent measured as percentage by weight of cement: 0.15% or 0.30%. The mixing time for Group 2 as measured after all ingredients including the air-entraining agent in the mixer, was fixed at 2 min.

The 16 mixes of Group 1 were designed to achieve a nominal 28 days concrete compressive strength of 30 MPa. In all 20 mixes of Groups 1 and 2, ASTM Type 1 Portland cement was used. The fine aggregate was natural sand with a bulk specific gravity of 2.55, an absorption capacity of 0.82%, and a fineness modulus of 3.22. The coarse aggregate used had a maximum size of 20 mm. The coarse aggregate was crushed limestone with a bulk specific gravity of 2.69 and an absorption capacity of 0.5%. Assuming oven-dry conditions for the aggregates, the mix proportions for Groups 1 and 2 are summarized in Table 4. The commercial air-entraining admixture used was Sika-Aer, which complies with ASTM C260-81. It will be referred to as Sika throughout the paper.

The amount of sulfates in the used and new engine oils was 4.6 and 1.6 mg/g, respectively. The amount of lead measured in milligrams per kilogram was less than 0.5 in both types of oil. The pH value was 6.8 for the used engine oil and 7.1 for the new engine oil.

The aggregates were oven dried at 105 °C for 24 h prior to batching. The aggregates were then cooled at room temperature before preparation of the concrete mixes took place. Mixing was conducted in the laboratory using a 5-foot^3 capacity concrete mixer. The casting procedure was the same for all the mixes. The (6×12 inches or 152.4×304.8 mm) cylinders and the (6×6×21 inches or 152.4×152.4×533.4 mm) beams used to test the properties of hardened concrete, were moist cured all the time until the day of testing.

The tested properties of fresh concrete included slump and air content. The ASTM test procedures used were C143 and C231, respectively. The tested properties of hardened concrete were the compression strength measured at 3, 7, 28 and 90 days; and the modulus of rupture or the flexural strength, the splitting tensile strength, and the modulus of elasticity, all measured at 28 days.

Table 3
Test variables and test results

Group	Mix no.	Mix properties				Fresh concrete properties		Hardened concrete properties						
		Air entraining agent	Dosage (%)	W/C[a] ratio	Mixing time (min)	Slump (cm)	Air content (%)	f_r[b] @ 28 days (MPa) (%)	f_{sp}[c] @ 28 days (MPa)	E[d] @ 28 days (MPa)	Compression strength @ 3 days (MPa)	Compression strength @ 7 days (MPa)	Compression strength @ 28 days (MPa)	Compression strength @ 90 days (MPa)
Group 1	1	None	-	0.62	2	10.5	2.3	6.9	2.6	32 678	11.5	17.1	24.9	28.5
	2	None	–	0.62	5	13.0	2.8	6.4	2.1	32 631	11.1	17.3	26.9	34.6
	3	Sika	0.075	0.62	2	19.5	10.5	4.9	1.7	21 386	6.5	8.6	11.8	17.1
	4	Sika	0.075	0.62	5	18.0	9.5	4.3	1.2	21 276	7.5	9.4	14.5	19.3
	5	Sika	0.15	0.62	2	19.5	11.0	4.6	1.3	22 832	5.5	7.4	12.5	15.0
	6	Sika	0.15	0.62	5	17.0	12.5	4.1	1.5	20 238	5.6	7.5	11.6	15.3
	7	Used oil	0.075	0.62	2	19.0	4.4	5.0	1.7	30 365	11.0	15.5	21.0	27.8
	8	Used oil	0.075	0.62	5	21.0	3.3	4.9	2.6	28 788	12.5	18.1	25.8	29.1
	9	Used oil	0.15	0.62	2	18.0	4.4	5.2	1.7	28 262	11.3	15.6	23.5	28.6
	10	Used oil	0.15	0.62	5	19.5	3.6	5.9	2.2	32 889	14.3	18.4	25.9	32.7
	11	Used oil	0.30	0.62	2	16.0	4.6	5.7	1.7	32 866	13.3	19.1	25.8	29.4
	12	New oil	0.075	0.62	2	20.5	2.5	5.6	2.2	26 840	10.8	14.3	20.8	30.1
	13	New oil	0.075	0.62	5	15.5	3.4	5.3	1.7	29 451	13.5	18.4	25.0	31.0
	14	New oil	0.15	0.62	2	22.0	3.5	5.9	2.0	28 694	11.6	17.6	23.8	30.6
	15	New oil	0.15	0.62	5	18.0	4.3	4.9	1.5	29 795	11.3	14.4	22.8	22.1
	16	New oil	0.30	0.62	2	16.0	5.7	6.1	1.7	32 011	13.5	17.1	26.3	29.1
Group 2	17	Used oil	0.15	0.59	2	9.0	4.4	7.0	2.6	34 298	15.3	19.4	30.2	34.5
	18	Used oil	0.30	0.59	2	9.0	4.8	6.9	2.6	32 885	12.8	19.7	26.5	30.1
	19	New oil	0.15	0.59	2	9.0	4.6	6.4	2.8	33 745	15.6	22.0	28.9	34.6
	20	New oil	0.30	0.59	2	9.5	4.5	7.1	2.5	32 211	13.1	20.8	26.2	27.5

[a] W/C=water/cement ratio.
[b] f_r=modulus of rupture or flexural strength.
[c] f_{sp}=splitting tensile strength.
[d] E=modulus of elasticity.

Table 4
Mix proportions for Groups 1 and 2

Material	Group 1 (kg/m³)	Group 2 (kg/m³)
Cement	372	372
Sand 0–5 mm	603	603
Rock 6–10 mm	491	491
Rock 12–20 mm	756	756
Water	231	219

The ASTM test procedures used were C39, C496, C78 and C469, respectively.

4. Test results

Results of tests of fresh and hardened concrete properties of all 20 mixes of Groups 1 and 2, are listed in Table 3. Each test result of the hardened concrete properties (flexural strength, tensile strength, and compression strength at four different ages) is the average of two test values.

4.1. Group 1

4.1.1. Fresh concrete properties

When no air-entraining agent was used, the slump of the mix was 10.5 cm for the 2-min mixing time and 13 cm for the 5-min mixing time, as shown in Table 3. The slump as a measure of fluidity and consistency of concrete improved to a value ranging from 16 to 22 cm when an air-entraining agent was used. The improvement was independent of whether Sika or the used/new engine oil was used. The improvement was also independent of the dosage of the air-entraining agent (0.075, 0.15 or 0.30%) and the mixing time (2 or 5 min). A typical variation of the slump vs. the air-entraining agent is shown in Fig. 1.

The amount of entrapped air in the control mix with no air-entraining agent increased from 2.3 to 2.8% as the mixing time increased from 2 to 5 min. The use of Sika, the chemical air-entraining admixture, increased the amount of entrained air to a value ranging from 9.5 to 12.5%. When used engine oil was added, the amount of entrained-air was 4.4–4.6% with 2-min mixing time (for all 3 dosages: 0.075, 0.15 and 0.30%) and dropped to 3.3–3.6% for the 5-min mixing time. When new engine oil was used, the amount of entrained air rose to 4.3 only when a dosage of 0.15% was used and the mixing time was 5 min. The amount was 5.7% when a dosage of 0.30% of the new engine oil was used. The amount of entrained air is shown in Fig. 2 for a dosage of 0.15% of the different air-entraining agents using a mixing time of 2 min.

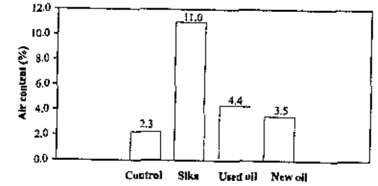

Fig. 2. Variation of air content for the different air-entraining agents, dosage = 0.15% and mixing time = 2 min.

4.1.2. Hardened concrete properties

In general and regardless of the type or dosage of the air-entraining agent used, the flexural strength or modulus of rupture dropped slightly when the mixing time was increased from 2 to 5 min. The only exception was when a dosage of 0.15% of used engine oil was used where the flexural strength increased from 5.2 to 5.9 MPa as the mixing time was increased from 2 to 5 min. The average values of the flexural strength for the different mixing times and different dosages of the air-entraining agent were 6.7, 4.5, 5.3 and 5.6 MPa, for concretes with no air entraining agent, with Sika, with used engine oil, and with new oil, respectively. The reduction in the average flexural strength relative to the control mix was 33, 21 and 16%, respectively. The corresponding variation is shown in Fig. 3.

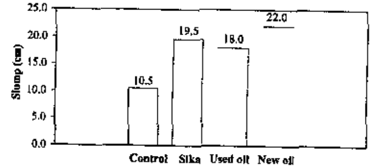

Fig. 1. Variation of slump for the different air-entraining agents, dosage = 0.15% and mixing time = 2 min.

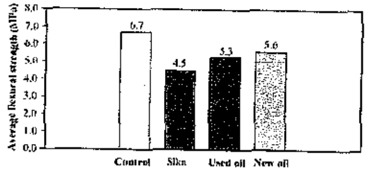

Fig. 3. Variation of the average flexural strength for the different air-entraining agents.

There was no clear trend in the values of the splitting tensile strength that could be related to the dosage of the air-entraining agent or the mixing time. The average value of the tensile strength for the control mix was 2.4 MPa. The average values were 1.4, 2 and 1.8 MPa when the air-entraining agent was Sika, used engine oil, or new oil, respectively (see Fig. 4). The losses in tensile strength relative to the control mix with no air-entraining agent were 42, 17 and 25%, respectively.

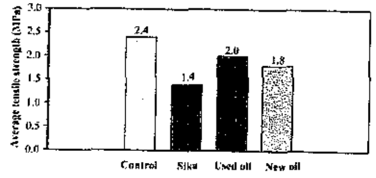

Fig. 4. Variation of the average tensile strength for the different air-entraining agents.

There was no clear change or trend in the values of the modulus of elasticity that could be related to the dosage of the air-entraining agent or the mixing time. The average value of the modulus of elasticity for the control mix was 32.4 GPa. The average values were 21.4, 30.7 and 29.4 GPa when the air-entraining agent was Sika, used engine oil, or new oil, respectively (see Fig. 5). The losses in the modulus of elasticity relative to the control mix with no air-entraining agent were 35, 6 and 10%, respectively.

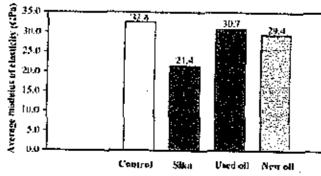

Fig. 5. Variation of the average modulus of elasticity for the different air-entraining agents.

The concrete compressive strength was measured for each mix at four different ages: 3, 7, 28 and 90 days (refer to Table 3). Except when new engine oil was used, there was a slight increase in the compression strength for all mixes when the mixing time was increased from 2 to 5 min. When the dosage of the chemical air-entraining admixture Sika was increased from 0.075 to 0.15%, there was a decrease in the strength value. However, when used or new engine oil were used, no significant change in the strength values could be related to the dosage. The variation of the concrete compressive strength with age, for a mixing time of 2 min, is shown in Fig. 6 for the control mix and for the mixes with 0.15% dosage of the different air-entraining agents. When the chemical air-entraining admixture Sika was used, the reduction in the concrete compression strength as compared with the control mix was approximately 50% at all ages. However, compressive strength variation curves for the used engine oil and the new engine oil mixes, are almost identical to that of the control mix (refer to Fig. 6).

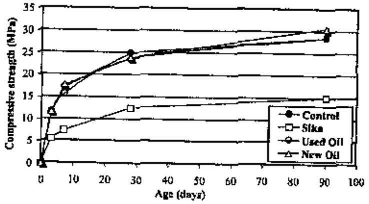

Fig. 6. Variation of the concrete compressive strength with age for the mixes of Group 1, air-entraining agent dosage = 0.15% and mixing time = 2 min.

Results of Group 1 mixes indicate that whereas the used engine oil almost doubled the fluidity and air content of the fresh concrete mix as compared with the control mix, it maintained the compressive strength at all tested ages. The average losses in the flexural strength, tensile strength, and the modulus of elasticity when used engine oil was used were 21, 17 and 6%, respectively. The average losses when new engine oil was used were 16, 25 and 10%, respectively. On the other hand, although the chemical air-entraining admixture Sika improved the fluidity and almost quadrupled the air content as compared with the control mix, however, it resulted in almost 50% loss in compressive strength at all ages. Also, the chemical admixture caused an average loss of 33, 42 and 35% in the flexural

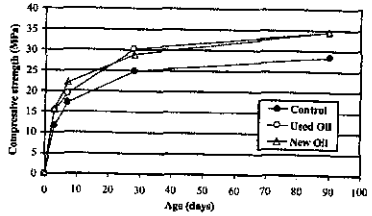

Fig. 7. Variation of the concrete compressive strength with age for the mixes of Group 2, oil dosage = 0.15% and mixing time = 2 min.

strength, tensile strength, and modulus of elasticity, respectively.

4.2. Group 2

Although the used engine oil did not result in similar improvement in air content as the chemical air-entraining admixture, still it did act as a chemical admixture improving fluidity and air content, and maintaining compressive strength while resulting in 6–21% losses in other hardened concrete strength values. It was necessary to design a new oil mix with lower water cement ratio to find out whether the improvement in fresh concrete properties could be maintained without incurring losses in hardened concrete strength values. Several oil mixes with different water cement ratios were tried until a 0.59 ratio and a 2-min mixing time were chosen. The variables of the four mixes of Group 2 were the type of the oil (used or new) and the oil dosage (0.15 or 0.30%). Test results of Group 2 are presented in Table 3.

The performances of the used and the new engine oil mixes were similar. Also, no significant difference in the test results could be attributed to the oil dosage. Discussion of the results is therefore limited to the used engine oil mix (W/C=0.59) with a dosage of 0.15% as compared with the control mix (W/C=0.62). The slump of the used engine oil mix was 9 cm as compared with 10.5 for the control mix. The air content of the used engine oil mix was 4.4%, almost double that of the control mix (2.3%). The flexural strength, tensile strength, and modulus of elasticity of the used engine oil mix were 7.0 MPa, 2.6 MPa and 34.3 GPa, respectively. The corresponding values for the control mix were almost identical: 6.9 MPa, 2.6 MPa and 32.7 GPa, respectively. The 28- and 90-day concrete compressive strength of the used engine oil mix improved by almost 20% as compared with the control mix (refer to Fig. 7).

5. Conclusions

To assess the effect of used engine oil on concrete properties, 20 concrete mixes were prepared. Tests were conducted on fresh and hardened concrete properties according to ASTM procedures.

When the water cement ratio was 0.62 for all companion mixes, identical except for the use of an air-entraining agent (none, commercial chemical air-entraining admixture, used engine oil, or new engine oil), the following conclusions were made:

1. The performance of the used engine oil and the new engine oil mixes were similar.
2. Used engine oil acted as a chemical plasticizer improving the fluidity and almost doubling the slump of the concrete mix.
3. Used engine oil increased the air content of the fresh concrete mix (almost double), whereas the commercial chemical air-entraining admixture almost quadrupled the air content.
4. Used engine oil resulted in average losses of 21, 17 and 6% in the values of the flexural strength, splitting tensile strength, and modulus of elasticity. The corresponding losses when the chemical air-entraining admixture was used were 33, 42 and 35%, respectively.
5. Used engine oil maintained the concrete compressive strength whereas the chemical air-entraining admixture caused approximately 50% loss in compressive strength at all ages.

When a water cement ratio of 0.59 was used for the oil mixes, the following conclusions were made after assessing and comparing the test results of these oil mixes with the control mix of a water cement ratio of 0.62:

1. The performance of the used engine oil and the new engine oil mixes were similar.
2. The fluidity of the used engine oil mix, as measured by the slump test, was maintained similar to that of the control mix.
3. The air content of the used engine oil mix was almost double that of the control mix.
4. Used engine oil with a water cement ratio of 0.59 maintained the flexural strength, splitting tensile strength, and modulus of elasticity of the control mix with water cement ratio of 0.62.
5. The 28- and 90-day concrete compressive strength of the used engine oil mix with a water cement ratio of 0.59 improved by almost 20% as compared with the control mix with a water cement ratio of 0.62.

In spite of the positive implications of the test results, more research is required before recommending the use of the engine oil waste as an admixture in the concrete industry. Research areas include:

1. Evaluation of the effect of used engine oil on the structural behavior of reinforced concrete elements.
2. Role of curing time and procedures on the effect of used engine oil on concrete properties.
3. Compatibility of used engine oil with other by-products or wastes used in concrete such as pozzolans (fly ash, silica fume, etc.).
4. Evaluation of the effect of adding used engine oil on durability of concrete exposed to carbonation, sulfate attack, corrosion, and other severe environment.
5. Evaluation of potential leaching of by-products from the resulting concrete mix.

Acknowledgments

The authors gratefully acknowledge the support of the University Research Board at the American University of Beirut for supporting this program. Also, the assistance of Mr Hilmi Khatib, Supervisor of the Materials Testing laboratory at AUB, is greatly appreciated. Appreciation is also extended to Miss Khouloud Karam and Mr Shadi Najjar for their support and assistance.

References

[1] Samarin A. Wastes in concrete: converting liabilities into assets. In: Dhir R, Jappy T, editors. Proceedings of the International Seminar on Exploiting Wastes in Concrete, Scotland. 1999. p. 1–21.

[2] El-Fadel M, Khoury R. Strategies for vehicle waste-oil management: a case study. Resources, conservation and recycling. Elsevier, in press.

[3] Mindess S, Young J. Concrete. Englewood Cliffs, New Jersey: Prentice-Hall, Inc, 1981.

[4] Kosmatka S, Panarese W. Design and control of concrete mixtures. Skokie, Illinois: Portland Cement Association, 1990.

[5] Rixom R, Mailvaganam N. Chemical admixtures for concrete. 3rd. New York: E & FN Spon, 1999.

[6] ACI Committee 318. Building code requirements for reinforced concrete and commentary (ACI 318R-02/ACI 318R-02). Farmington Hills, Michigan: American Concrete Institute, 2002.