EFFECT OF HIGH VOLUME FLY ASH ON PERFORMANCE OF GROUT AND MASONRY CEMENT MORTAR

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ABSTRACT

Grout and mortar often selected for building repair and restoration works. However, these materials are also deteriorating and failed similarly as per the parent concrete or masonry structure due to environmental exposure, electrochemical reactions and mechanical loading. Previous studies and the available literature indicate that the failure of such repair material is mainly due to improper selection of material without knowing the material's ability in order to improve the repair grout and masonry cement mortar is currently lacking. To address this, high volume fly ash (HVFA) in repair grout and masonry cement mortar is introduced. HVFA is selected as fly ash (FA) waste is still abundance and its unique spherical shape and pozzolanic property is suitable for this study. This research is first carried out by investigating the characteristics of the binders using X-ray Fluorescence Spectrometry (XRF), Scanning Electron Microscope (SEM) and X-Ray Diffraction (XRD). The performance evaluation of grout and mortar has been accomplished with specimens where Ordinary Portland Cement (OPC) and masonry cement (MC) is replaced by Class F FA up to 50%. The grout and mortar were subjected to workability test such as flow, viscosity and spread followed by mechanical properties such as compressive strength, bond strength and flexural strength. Durability of the material is finally evaluated by exposing them to aggressive substances such as acid, chloride and sulphate, and high temperature up to 1000 °C. HVFA results an excellent grout flow time with a reduction over 30% in flow time and maintained a fluid Bingham behaviour over 1 hour. Meanwhile, the mortar has an increment of 15% in spread. The compressive strength, flexural and splitting tensile shows that grout with 40% FA is close to the control value, while 50% FA grout is slightly lower at the end of 360 days. Opposite result is found with masonry cement mortar where HVFA exceeded control at 90 days. HVFA grout experienced approximately 50% lower amount of autogenous shrinkage and time to crack in drying shrinkage evaluation. The porosity of the HVFA grout is reducing with inclusion of FA at 360 days. While the mortar being air-entrained material, slightly affected by fly ash properties that results in additional water absorption. The HVFA's pozzolanic, filler and dilution effect has contributed to remarkable performance against aggressive substances and condition for both materials. Grout being loaded with cement has 40% to 80% higher resistance to the chemical substances as compared to control, while mortar is the range of 80% to 100%. Test result on temperature rise shows HVFA able to reduce over 20 °C in peak temperature. Additionally, the thermal insulation behaviour of HVFA grout indicates slower response to heating by having additional 20 hours in time to reach 100 °C. The comparison between grout and masonry mortar shows good similarity, particularly in chemical resistance. Conclusively, the performance of HVFA in grout and masonry cement mortar has found to be satisfactory and can be used for concrete and masonry repair with increased durability. Both materials can be expected to compliment a sustaining building repair and restoration work.

ABSTRAK

Grout dan mortar kerap dipilih untuk membaik pulih bangunan. Walaubagaimanapun, bahan-bahan ini juga mengalami kemerosotan dan kegagalan sama seperti konkrit atau struktur bata akibat pendedahan kepada alam sekitar, tindak balas elektrokimia dan beban mekanikal. Kajian dan literatur terdahulu menunjukkan bahawa kegagalan bahan pembaikan seperti ini disebabkan oleh pemilihan bahan yang tidak sesuai dan pemahaman untuk menambahbaik grout and mortar masih berkurangan. Untuk menangani masalah ini, "high volume fly ash" (HVFA) telah diperkenalkan dalam grout pembaikan dan mortar untuk kerja bata. HVFA telah dipilih disebabkan sisa "fly ash" (FA) masih banyak didapati dan dalam bentuk yang unik serta sifat "pozzolanic" adalah ciri-ciri yang sesuai untuk kajian ini. Penyelidikan ini dimulakan dengan menyiasat ciri-ciri simen and FA dengan mengunakan X-ray Spectrometry Fluorescence (XRF), Scanning Electron Microscope (SEM) dan X-Ray Diffraction (XRD). Penilaian prestasi grout dan mortar telah dicapai di mana Simen Portland Biasa (OPC) dan masonry cement (MC) digantikan dengan FA Kelas F sehingga 50%. Grout dan mortar tertakluk kepada ujian kebolehkerjaan seperti aliran, kelikatan dan penyebaran diikuti oleh sifat-sifat mekanikal seperti kekuatan mampatan, kekuatan ikatan dan kekuatan lenturan. Ketahanlasakan bahan-bahan tersebut akhirnya dinilai dengan mendedahkanya kepada bahan kimia agresif seperti asid, klorida dan sulfat serta suhu setinggi 1000 °C. Keputusan HVFA menunjukan aliran grout yang sangat baik dengan pengurangan 30% masa aliran dan mengekalkan sifat cecair Bingham selepas 1 jam. Selain itu, mortar mempunyai peningkatan penyebaran sehingga 15%. Kekuatan mampatan, tegangan lenturan dan pemisahan pada 360 hari menunjukan grout dengan 40% FA hampir sama dengan sampel kawalan, manakala grout dengan 50% FA menunjukan kekuatan lebih rendah. Keputusan disebaliknya diperolehi dengan masonry mortar di mana kekuatan HVFA melebihi nilai kawalan selepas 90 hari. Grout HVFA mengalami pengecutan autogenous dan masa retakan sebanyak 50% lebih rendah didalam penilaian pengecutan pengeringan. Ronggaan pada grout HVFA bekurangan dengan kemasukan FA selepas 360 hari. Sementara itu, mortar yang mengandungi pengudaraan sedikit terjejas oleh sifat FA yang menyebabkan penyerapan air bertambah. Kesan pozzolanic, isian dan pencairan HVFA telah menyumbang kepada ketahanlasakan yang luar biasa terhadap bahan kimia dan keadaan yang agresif untuk kedua-dua bahan. Grout yang mempunyai kandungan simen yang tinggi, mempunyai 40% hingga 80% rintangan manakala mortar mempunyai rintangan antara 80 hingga 100% lebih baik terhadap bahan kimia berbanding dengan nilai kawalan. Hasil ujian pada peningkatan suhu menunjukkan HVFA mampu mengurangkan lebih dari 20 °C suhu puncak. Selain itu, sifat penebat haba HVFA grout menunjukkan tindak balas yang perlahan dan memerlukan tambahan masa sebanyak 20 jam untuk mencapai suhu 100 °C. Perbandingan antara grout dan mortar menunjukkan kesamaan, terutamanya dalam rintangan terhadap bahan kimia. Kesimpulanya, prestasi HVFA di dalam grout dan mortar didapati memuaskan dan boleh digunakan untuk pembaikan konkrit dan kerja bata dengan peningkatan ketahanlasakan. Kedua-dua bahan boleh membantu dalam kerja membaik pulih bangunan yang mampan.

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LIST OF ABBREVIATIONS

ASTM	-	American Society for Testing and Materials
BS	-	British Standard
ACI	-	American Concrete Institute
BS EN	-	British Standard, Eurocode
EDS	-	Energy Dispersive X-Ray Spectroscopy
FA	-	Fly ash
GGBS	-	Ground granulated blast furnace slag
SEM	-	Scanning Electron Microscopy
XRD	-	X-Ray Diffraction
XRF	-	X-ray Fluorescence Spectrometry
PFA	-	Pulverised Fuel Ash
OPC	-	Ordinary Portland Cement
MC	-	Masonry cement
HVFA	-	High volume fly ash
MW	-	Megawatt
LOI	-	Loss on ignition
SAI	-	Strength activity index
SP	-	Superplasticiser
SF	-	Silica Fume
POFA	-	Palm oil fuel ash
POCP	-	Palm oil clinker powder
PSD	-	Particle size distributions

LIST OF SYMBOLS

μm	-	Micrometre
cm^2/g	-	Centimetre square per gram
N/s	-	Newton per second
τ	-	Shear stress
γ	-	Shear rate
τ_o	-	Bingham constant
μ	-	Plastic viscosity
N	-	Newton
^oC	-	Degree Celsius
S_f	-	Flexural strength
P	-	Load
T	-	Splitting tensile strength
C-S-H	-	Calcium-silicate-hydrate
C_3A	-	Tri-calcium aluminate
$CaCO_3$	-	Calcium carbonate
CaO	-	Calcium oxide
Ca	-	Calcium
C_4AF	-	Tetra-calcium aluminate Ferrite
C_2S	-	Di-calcium silicate
C_3S	-	Tri-calcium silicate
$Ca(OH)_2$	-	Calcium hydroxide
CO_2	-	Carbon dioxide
H_2SO_4	-	Sulphuric acid
$MgSO_4$	-	Magnesium sulphate
UV	-	Ultraviolet

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CHAPTER 1

INTRODUCTION

1.1 Problem Background

Certainly, cement-based materials are by far the most important building material. Worldwide, more than 10 billion tons are produced each year. The major application of cement composites can be grouped into concrete, grout and mortar. Minimising the environmental impact and energy and CO_2 intensity of cement used for construction is becoming increasingly important as resources decline and the impact of greenhouse emissions becomes more evident. Moreover, durability deficiency of cement composites, which failed prematurely, results in consumptions of additional natural resources, is a major concern in development of sustainable infrastructure systems. This because the repeated repairs carried out on the building requires additional raw material for the manufacturing of the repair material which is not efficient.

Despite the expanding need for concrete repair, the lack of comprehensive data leaves some uncertainty as to how to proceed with the design and execution of durable repairs. The extreme weather conditions in tropical climate make it even more difficult. To achieve a lasting repair, it is essential that the properties of the repair material are properly evaluated so that the repair material can withstand the stresses resulting from the attack from the environment over a designated period of time, without experiencing distress and deterioration.

It is also important to understand that the durability of the building is not the function of concrete alone, but also as to how its components are responding to the exposure conditions of the structure. In this particular, grout and mortar that are used to repair concrete are generally failing due to aggressive condition with equal threat as to concrete. Soil, undersea piers and oil-well grouting requires enormous amounts of cement and are examples of areas where the grout is used. Such environment can be harmful to cement-based materials. However, very little is known on the behaviour of such materials in the aggressive conditions or the performance evaluation after applications. Moreover, in recent times, the use of masonry cement (MC) for plastering mortar has been introduced as a placement for Ordinary Portland Cement (OPC). Although it is extensively used, the durability characterises of the material is not established. An understanding of grouts or masonry mortar durability is fundamental to establish the service life of repaired structures. Conventionally, repair materials are used for structural repairs that are capable of carrying a structural load or forming an integral part of a structure. Knowledge of the durability is the key to the long-term performance minimizing the rate of deterioration. Deterioration can be caused by physical or chemical mechanisms. Many of these types of deterioration are time-dependent such as environmental exposure durations. Some types affect the structural integrity, while others affect the chemical stability. For example, high temperature deteriorates the integrity while chemical such as sulphate, disrupts the chemical stability of calcium hydroxide inside the repair material. These differences are important when considering the cement-based materials that will be placed in the aggressive environment.

1.2 Background of the Study

Current global researches are very much aligned to the need of modern civil engineering challenges that emphasis sustainability and development of new materials are expected to be more durable while uses fewer resources. This new challenge has sparked the interest of various field experts in researching new composite materials that has lower carbon foot-print and outstanding durability.

In this study, sanded grout that is suitable for structural repairs such as column enlargement and port restoration that requires high fluidity material was selected. Meanwhile, masonry mortar that is suitable for non-structural application such as plastering was selected. Fly ash from a coal fired power plant was used to carry out partial cement replacement in both materials. Fly ash was selected as the material is abundantly available in Malaysia and being actively dumped due to lack of consumption and recent expansions in the coal fired power capacity. This results in excess that could not be recovered to be used in concrete alone.

Although fly ash has been used for a long time; this noble practice is hardly applied in repair material such as sanded grout and masonry cement mortar. Limited data is available on the performance evaluation of such grouting and mortar material in aggressive environment. Particularly when comes to grout, rheology is critical and fly ash is an important material that could help in the concrete repair application. After all, fly ash is still abundantly available and being dumped actively in Malaysia and globally. This is what the study is trying to bridge the gap. The research believes that any new knowledge that could help the consumption of fly ash is always beneficial although it is not the primary aim of the research.

1.3 Background of the Problem

Material engineers lack looking on durability problem of other components of civil engineering material such as repair grout and masonry mortar as there are lack of code of practices on durability for such materials and increasing amount of repair materials deterioration reported. Typically, materials such as grout and mortar used are made solely from OPC and the use of composite cements for such applications is still lacking. Since OPC grout or mortar is more susceptible for deterioration, the use of blended cement for such repair material could be beneficial. The following highlights the problem related to these materials.

i. Grouting materials contains approximately 50% of cement, which translates into about 1000 kg/m^3. As compared to concrete that typically has a cement content of 400 kg/m^3, this high cement content makes the material more vulnerable to large possibilities of durability problems as compared to concrete. However, there is lack of studies on the durability of grouts used for concrete repairs.

ii. Masonry mortar is often made with OPC. In recent times, the use of masonry cement made of different chemistry has been introduced. However, there are lack of studies on the durability of masonry mortar made with masonry cement is available. The potential use of masonry cement mortar in the repair application and as a protection material needs to be exploited. Moreover, it has been reported that mortar used for plastering do deteriorates under certain circumstances.

iii. Both grout and masonry mortars have some similarities, both uses same grading of fillers, however, special additives and type of primary binder set them apart. Therefore, as indicated by previous studies that certain supplementary cementitious materials such fly ash can significantly affect the material properties; this must be further investigated for the use in the grouting and plastering material.

iv. Although fly ash is used in many places, the quantity is often limited to around 30% including in concrete and very scant information can be found on the use of HVFA in repair grout or masonry cement mortar. Therefore, high volume fly ash concept will be exploited in grouting and masonry mortar system that is applicable for repair and protection works.

v. Solid waste management is a global challenge and fly ash is big part it. Globally the use of coal is expanding radically, including in Malaysia with commissioning of expansion of coal fired power plant. Considering the amount of fly ash waste materials available in Malaysia and the desire to address the environmental problems posed by this waste and even though there is a clear economic and environmental benefit associated with the use of such waste materials, limited information is available on high volume application of such materials.

1.4 Aim and Objective of the Study

The ultimate aim of the study is to make sanded concrete repair grout and the masonry cement mortar a better engineered material as compared to concrete. This will be done by investigating the fresh state, strength and durability of grout and masonry mortar containing high volume fly ash. Additionally, the main purpose of this work is to explore the use of high-volume fly ash in grout and masonry mortar that will be beneficial for repair works or concrete protection works. It is carried out by studying the effect of high volume fly ash on the workability, strength and durability of the grout and mortar. In order to accomplish the overall purpose, the following objectives are included in the evaluation of these materials.

i. To characterize the micro-structure and the physio-chemical characteristics of the binders (Ordinary Portland Cement, Masonry Cement and fly ash) and the repair materials containing HVFA.

ii. To determine the optimum level of mixture proportions for OPC grout and masonry cement mortar using fly ash by studying the stability, rheology and strength properties of grout and mortar for variable duration.

iii. To investigate the behaviour of the grout and mortar containing high volume fly ash under aggressive environment in a long-term exposure setting.

1.5 Scope of Study

The study would be experimental in nature and focus on the development and use of high volume fly ash in sanded repair grout and masonry cement mortar. Replacement levels of cement with fly ash ranges from 0 to 50%. The study emphasizes rheology, strength and durability behaviour the grout and mortar, which is believed to be within the limits set by the objectives. The results of the study cannot be applied in general terms, except for PFA that possess similar characteristics. Cost effectiveness of materials has not been considered in this study. This of course does not intend to neglect the study economy to background, but rather it is believed that technical issues have to be understood and fixed right before the economic aspect of the study is determined. Extent of content that will be covered by the means of the scope of the research is presented in Table 1.1.

Table 1.1 Summary of scope of study

Criteria		**Limitation**	
Primary Binder	Grout	OPC Class 52.5N	high clinker content – in loading capacity repairs
	Mortar	Masonry Cement Class 22.5X	low clinker content – for non-structural repairs
Supplementary Cementitious Material		Fly ash from Jimah Power Plant (Due as latest power plant in Malaysia)	
Partial cement replacement level		Up to 50%, with increment of 10% of weight, but emphasising HVFA material with 40 & 50% fly ash.	
Mix proportions	Grout	OPC, fly ash, sand, admixtures, water	
	Mortar	Masonry cement, fly ash, sand, water	
Admixtures used	Grout	Superplasticiser & expansion agent	
	Mortar	NIL	
Evaluation		Workability, mechanical properties and durability	
Exposure condition		Natural: Sea tidal zone	
		Artificial: Indoor	
Aggressive substances		Sulphuric acid, magnesium sulphate, calcium chloride	
Subjected to fire resistance		Heating up to 1000 °C	
Long term exposure durations		360 Days (sulphuric acid, calcium chloride) 720 Days (magnesium sulphate)	

1.6 Significance of the Study

The significant findings of this research will be beneficial in the following ways:

i. Overcome common durability deficiency in repair materials and assist material engineers to select robust repair materials which could provide longer service life compared to current conventional materials. This contributes to the body of knowledge on extended use of HVFA in a durable concrete repair grout and masonry mortars.

ii. Encourage the use of masonry cement with HVFA for concrete or brick protection. This will further consumption of the fly ash, particularly in current times where the ash output from the coal fired plant is at serious increasing trend.

iii. Partial replacement of cement with fly ash will result in lower emission of carbon dioxide from the cement manufacturing industry and lower consumption of natural resources such as limestone as cement's main raw material.

iv. Due to high adoptability, the final product can be easily commercialized for mutual benefit of the institution and the industry. This will facilitate the introduction of practically functional green materials in the construction industry that can further help the global initiative on green building index system.

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