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A Review on Strength and Durability ofGeopolymer Concrete

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ABSTRACT
This paper presents a review on strength and durability of Geopolymer concrete. Geopolymer concrete is used as it can be eco-friendly and economic alternative to the ordinary Portland based cement concrete. The Geopolymer concrete was prepared with Fly ash or GGBS in combination with rice husk ash or bagasse ash as the primary binder instead of cement. The effect of curing temperature on the compressive strength of Geopolymer concrete was studied in addition to the flexural and split tensile strengths. The strength characteristic under G40 (which is equivalent to M40 of normal OPC based cement concrete) is considered here for the study. The strength of the concrete namely compressive, split tensile and flexure strength tests were carried out at the age of 7days and 28 days .The results which intern say that the Geopolymer concrete will have more strength than the conventional concrete when temperature curing (60^0c - 80^0c) is applied on geopolymer concrete. The durability of geopolymer concrete is studied by exposure of geopolymer concrete to acids and sulphates, and it is found that geoplymer concrete shoes more resistance to acid and sulphate attacks compared to conventional concrete.

Keywords- Geopolymer concrete, strength, durability

I. INTRODUCTION

Ordinary Portland cement is produced through the crushing, grinding and heating of the limestone. From past 3000 years concrete is used as it is Durable, Flexible and Strong. Over 3- quarter of the tonne of carbon dioxide is released into our earth's atmosphere every year, this is equivalent to the emissions of carbon dioxide from 0.55 billion combustion engine cars. This allow us to study the properties, chemical performance, strength of Geopolymer concrete, these tools are allowing us to produce the next generation of high-performance materials. Materials such as Fly ash, Bagasse-Ash are the focusof our research geopolymer.

By the use of industrial by product as binder material >75% of carbon dioxide which is released from OPC can be reduced.

Davidovits in 1979 proposed that an alkaline liquid could be used to react with silicon and aluminum as source material with byproduct materials such as fly ash, GGBS and rice husk ash etc.to produce binders.

Normally sodium hydroxide with sodium silicate at liquid ratio of 2.5 is used as a alkaline liquids. Sodium is preferred over potassium mainly because it is cheaper. The geopolymer concrete is to be such that it should obtain high strength and alsothe geopolymer concrete should be durable. The durableconcrete means the concrete should provide high resistance towards the weathering action, acid attacks, deterioration and exposed to the harsh environment.

II. GEOPOLYMER CONCRETE

Geopolymer concrete is environmentally friendly and economical building materials. It is one of the alternatives to replace ordinary Portland cement concrete. Geopolymer concrete is made up of source materials, fly ash, GGBS, and alkaline liquids which are the combination of sodium silicate and sodium hydroxide which form the binder due to polymerization process. The binders created were termed as "Geopolymers".

III. REVIEW OF LITERATURE

A Chithambar Ganesh, K Rajesh Kumar, (2020) conducted an experiment on Durability Studies on the Hybrid Fiber reinforced

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Geopolymer concrete made of M-sand under ambient curing. The materials used for this investigation are GGBS, M- sand, Coarse aggregate, Sodium hydroxide pellets, Sodium hydroxide of 13 Molarity, sodium silicate and metallic and non- metallic fibers are used. The test specimens cast are cube of 100mm X 100 mm to study the water absorption, Disc 100 x 50 mm to study Sorptivity, Disc 100 x 50 mm to study Rapid chloride penetration, cube of 100 mm X 100 mm to study the Acid resistance, cube of 100 mm X 100 mm to study the Sulphate resistance and cube of 100 mm X 100 mm to study the Marine attack. Geopolymer concrete reinforced with glass fibers exhibited least Water absorption capacity than the other hybrid fiber reinforced geopolymer concrete samples. Geopolymer concrete reinforced with glass fibers resisted the entry of charges in to the concrete than the other types of geopolymer concrete. All the hybrid fiber reinforced geopolymer concrete exhibited excellent resistance to acid attack, sulphate attack and marine attack. [1]

KOLLI RAMUJEE (2018) Explains the properties of fly ash based geopolymer concrete,activation of aluminosilicate materials such as fly ash, blast furnace slag, and metakaolin using alkaline solutions to produce binders free of portland cement is a major advancement towards increasing use of industrial waste products and reducing the adverse impacts of cement production.Materials used for this experiments are fly ash ash ($394kg/m^3$),aggregates,sodium hydroxide(8M) and sodium silicate and mix proportion for M40 is 1:1:64:3.04 and liquid to binder ratio is 0.40.The test specimens cast to study the compressive strength ,flexural strength,splittensile strength, modulus of elasticity and also water absorption and sportivity. The GPC attains its target strength much faster under heat cured condition compared to ambient cured condition. The sorptivity and water absorption characteristics of geopolymer concrete performed better compared to OPC concrete. [9]

Sandeep L. Hake, P. R. Awasarmal, R. M. Damgir (2019) conducted an experiment on Durability study on fly ash based geopolymer concrete for acidic environment. Materials used for this experiment are Fly ash, combination of sodium hydroxide and sodium silicate solutions, Fine and coarse aggregates. The curing hours maintained 18 hours for different types of curing. The test specimens cast are the cubes of size 150 mm X 150 mm X 150 mm to study the Compressive strength of concrete. The geopolymer cube after the testing age was immersed into sulfuric and hydrochloric acidic condition for 0, 45, 90, 135 and 190 days. It is also observed that the target strength is achieved for 90C on oven curing in 18 hours and In steam curing target strength is achieved for 1000c in 18 hours. The sulfuric corrosive influences the compressive quality and also weight misfortunes of fly based geopolymer concrete. It was seen that the level of weight and quality decrease was more on account of oven curing as contrast with another kind of curing. [14]

D JAISHREE AND G.REKHA (2018) Explain characteristics of geopolymer concrete by partial replacement of geopolymer concrete with various percentage. The main objective of this project is to study the various properties of the Geopolymer Concrete and compare it with the OPC concrete. Materials were used flyash($394.28Kg/m^3$), aggregates and alkaline liquids. The mechanical properties of concrete are compressive strength, split tensile strength and flexural strength. The curing period of concrete specimens were taken at 7, 14 and 28 days and tests were conducted for the specimens size of cube is 150mm*150mm*150mm, for beam 150mm*150mm*700mm and for cylinder 150mm*300mm. Geopolymer concrete manufactured with fly ash ratios 1:1.640:3.046 and 8, 10 and 12 mole solution attained the maximum strength which was lesser than the conventional concrete. Longer curing time improved the polymerization process resulting in higher compressive strength. The rate of increase in strength was rapid up to 24 hrs of curing time. Fly ash based geopolymer concrete as excellent compressive strength and tensile strength which is suitable for structural application. [4]

R. Manickavasagam and G. Mohankumar(2017) Explain the Durability studies on the high calcium flyash based geopolymer concrete. High calcium flyash based GPC is observed to possess superior durability related properties over OPCC.Materials used in this experiments are high calcium flyash,aggregates and alkaline liquids.Tests conducted are saturated water absorption,sulphuric acid resistance and corrosion resistance by polarization test. High calcium flyash can be used as source material for making GPC similar to low calcium flyash for developing the required design strength. High calcium flyash has compatibility with the alkaline solution and other constituents. High calcium flyash has compatibility with the alkaline solution and other constituents.

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The corrosion resistance of GPC is 16% to 24% higher than the OPCC. [13]

Ajay Kumar Singh (2016) conducted a experimental study on Strength and Durability Test of Fly Ash and GGBS Based Geopolymer Concrete. Materials used in this experiment are Flyash, GGBS, Alkaline solution, fine aggregates, coarse aggregate and Admixtures. Compression Strength test, Split Tensile test, Acid attack and Durability test are conducted in this experiment. The Geopolymer cubes were cured at the sun for 28 days. After 28 days the cubes attains compressive strength of 47.40 MPa. The split tensile strength can be calculated by: Fst=2P/(πLD). The specimen were immersed inthe 3% HCL, 3% H2SO4 and 3% HNO3 and it is tested in compression testing machine to find durability. The initial and final setting time of the Geo Polymer concrete is low. Geopolymer concrete shows greater resistance to acid environment as compared to ordinary Portland cement. Compressive strength of GGBS added geopolymer concrete is high with increase in alkaline to binder ratio. With the addition of 40% GGBS there is increase in compressive strength of geopolymer concrete. The geopolymer concrete is light in colour and surface are more smooth than ordinary Portland cement. Curing temperature and method of curing influences the compressive strength of the specimens. [2]

Ganesan Lavanya and Josephraj Jegan(2016) conducted a experimental study on Durability of High Calcium Fly Ash Based Geopolymer Concrete. Materials used for in study are Class C Flyash, Alkaline solution, Fine aggregate and Coarse aggregate. The cube specimens of size 150 × 150 × 150 mm and cylinder of size 100 × 200 mm were casted. The sorptivity tests were undertaken for cylindrical specimens with 100 mm diameter and 50 mm height in accordance with ASTM C1585-
04. The quantity of water absorbed in a time period of 30 minutes was measured. % water absorption = $[W2 - W1/W1]$
× 100, sorptivity coefficient was calculated using the equations given as follows: $S = I/\sqrt{t}$. In this study it is concluded that the GPC and OPC mixes indicated minor changes in weight and strength when the specimens were exposed to sulphuric acid and magnesium sulphate. The compressive strength loss from 7 to 45 days of exposure in sulphuric acid was in the range of 18 to 28% in OPC, whereas it was about 12 to 20% in GPC. The compressive strength loss from 7 to 45 days of exposure in magnesium sulphate was in the range of 5 to 25% in OPC, whereas it was about 5 to 12% in GPC. he water absorption and sorptivity of geopolymer concrete showed lower water absorption and sorptivity when compared to ordinary Portland cement concrete for M40 grade concrete. [6]

N P Rajamane (2016) explains production of cement is highly energy intensive process. In addition to this ordinary Portland cement concrete is highly prone to sulphate attack at prolonged exposure. He investigates the geopolymeric reaction of Fly ash and GGBS with the help of sodium hydroxide silicate based alkaline activator solutions. The GPC mixes were produced using equipment similar to those used for production of conventional cement concretes. As the GPC do not have any Portland cement, they can be considered as less energy intensive, since Portland cement is a highly intensive energy material next to aluminum and steel. The GPC and PPCC mixes indicated minor changes in weight but significant reduction in compressive strength after exposure to sodium and magnesium sulphate. The PPCC had strength losses of 9% to 39% whereas, GPC showed 1.4% to 21.3%, depending upon the type of sulphate and exposure period for sulphates. Decalcination of C-S-H gel and formation of gypsum and ettringite in P-C based concrete and release of alkalis from geo polymers into solution in GPC considered as major reason for deterioration of strength on attack by sodium sulphate. However, GPC can be considered as more resistant to attack by sodium sulphate as compared to conventional cement concrete. The GPC and PPCC mixes are found to be almost similar in respect to resistance to attack by 5% magnesium sulphate solution. There were minor changes in weight but significant reduction in compressive strength after 90 days of exposure.. GPC have higher strength development rate than that PPCC and this may be advantageously exploitedin actual constructions.

N.S. Kumaravel , P. Girija and B. Anandha Kumar (2015) conducted a experimental study on Durability performance of various grade of geopolymer concrete to resistance of acid and salt. Materials used in this study are Fly ash, Coarse aggregate, Fine aggregate, alkaline liquid and Super Plasticizer. The test specimens cast are the cubes of size 150 mm X 150 mm X 150 mm and cylinders of size 100 mm diameter, 200 mm height to study the Compressive strength of concrete. The weight of geopolymer concrete decreases, when the acid concentration increases. The geopolymer concrete and cement concrete in

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different grade of concrete is minor changes in weight and strength when the specimens are exposed to hydrochloric acid and magnesium sulphate. The deterioration of geopolymer concrete assessed against 5% of magnesium sulphate solution and found that the weight loss and compressive strength are less when compared to cement concrete. The compressive strength loss for the specimens exposed in magnesium sulphate is in the range of 5 to10% in CC, where as it was about 4 to 10% in GPC. GPC is the industrial waste by-product for producing the binding material in concrete, so it can be considered as eco-friendly material. [11]

V.BHIKSMA AND T.NAVVENKUMAR(2014) The cement industry accounts for a considerable share for CO_2 emissions due to cement's high environmental carbon content,So that utilization of industrial waste material such as fly ash, ground granulated blast furnace slag (GGBS), silica fume etc., as a replacement will lead to substantial reductions in greenhouse gas emissions.This paper investigates the mechanical properties of flyash based geopolymer and materials used for this experiments are GGBS(27.5%), flyash(348kg/m^3),aggregates and sodium hydroxide(8M).The test specimens cast are the cubes of 150mm*150mm*150mm to study the compressive strength ,flexure and split tensile strength and tested at 7,14 and 28days. From test results concluded that workablility of the geopolymer concrete same as that of conventional concrete and 28-day compressive strength results were more than values recommended by IS 456-2000. [17]

T. Bakharev (2014) explains premature of Portland cement and blended cement under sulphate attack. The durability of geopolymer materials manufactured using class F-fly ash and alkaline activators when exposed to sulphate environment is studied. Fluctuation of strength and micro structural changes took place in 5% solutions of sodium sulphate and magnesium sulphate. Diffusion of alkali ions into the solution caused significant stresses and formation of deep vertical cracks in the specimens prepared using a mixture of sodium and potassium hydroxides. The best performance in different sulfate solutions was observed in the geopolymer material prepared with sodium hydroxide and cured at elevated temperature. These specimens had 4% to 12% increase if strength when immersed into sulphate solutions. Specimens prepared with sodium hydroxide were more stable in sulphate solutions than specimens prepared using sodium silicate or mixture of sodium and potassium hydroxide solutions.

KOLLI RAMUJEE (2014) In terms of reducing global warming, the geopolymer technology could reduce the CO2 emission to the atmosphere caused by cement and aggregates industries by 80%.Materials used for this experiments are low calcium flyash(394.3 Kg/m^3),aggregates,alkaline liquids and liquid to binder ratio is 0.4. Compressive strength tests were performed at the age of, 7 and 28 days in accordance with IS:516-1959. The compressive strength attained at 28 days for Geopolymer concrete under ambient curing is almost equal to compressive strength achieved by Geopolymer concrete at 7 days. The Water/binder ratio 0.21 and Alkaline liquid to flyash ratio of 0.40 are suggested for G40 which indicates improvement in compressive strength of geopolymer concrete can be achieved by decreasing water binder ratio. [8]

P.Rachel and Dr.P.Partheeban (2013) conducted an Experiment on Durability Study of Low Calcium Flyash Based Geopolymer Concrete. The materials used for this experiment are Low-calcium fly ash-based geopolymer concrete, combination of sodium silicate solution and sodium hydroxide solution was chosen as the alkaline liquid. The test specimens cast are the Cubes of 150X150X150mm, Cylinders of 100x120mm and Beams of 100x100x500mm to study the Compressive strength, Split tensile strength and Flexure strength. The 7 and 28 days average compressive strength of hot air oven specimens were higher than that of ambient cured specimens respectively, which indicates that heat curing is necessary for achieving strength for geopolymer concrete. The 7- and 28-days average split tensile strength of hot air oven specimens was higher that of ambient cured specimens respectively. The flexural strength is high for 28day strength. In this it is concluded that geopolymer concrete posses excellent durability as a construction material. Geopolymer concrete is eco-friendly as the usage of ordinary Portland cement is completely avoided and therefore emission of co2 can be controlled there by reducing pollution. [12]

Kunal Kupwade-Patil (2013) explains the durability of ordinary Portland. Alkali silica reaction takes place between the hydroxyl ions of pore water and certain form of silica. This causes

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premature of structure. They carry experimental investigation for alkali silica reaction between reactive aggregate and geo polymer. The matrix specimens were prepared by using class 1 and 2 fly ash stockpiles. Mechanical testing included potential reactivity of aggregates through length change and compression test measurements, as per ASTM standards. Result suggests that the extent of alkalisilica reaction in geopolymer is lower than in the case ofordinary Portland cement-based concrete and well below the ASTM specified threshold**.** OPC concrete exhibited higher average expansion by a factor of 6 compared to GPC specimens following a 90-day exposure to 1 molar sodium hydroxide solution at 80°C. XRD analysis indicate the presence of formation of zeolites. In particular, the analysis phase found in GPC can cause some expansion. The greater the expansion, the greater the Sodium Hydroxide infiltration into the matrix. Thus, a slight-to-moderate expansion of GPC in the presence of sodium hydroxide and elevated temperature results in the re-initiation of the geo polymerization process of unreacted fly ash particles, leading to lower porosity and higher strength.

U R Kawade (2013) explains enormous demand for mineral admixture and this demand is expected to increase in future. This paper aims at finding an alternative to replace cement. The sugarcane Bagasse is used as partial replacement to cement. The analyses on the effect of SCBA in concrete by partial replacement of cement at different ratios such as 0%, 10%, 15%, 20%, 25% and 30% by weight casted and tested at different days of curing in water at 7, 28, 56 and 90 Days. The mix design of the concrete is done the as per Indian standard guidelines for M20, M30, and M40 grade. The result obtained shows that SCBA concrete had higher strength compared to the ordinary cement. The strength increases in the SCBA concrete with increase in grade of concrete up to 15% replacement, above that the strength declines irrespective of any grade of cement. Therefore, optimal level was achieved with 15% replacement. Partial replacement of cement by SCBA increases workability of concrete therefore use of superplasticizer is not essential**.** [18]

IV. RESULTS AND DISCUSSION

Compression test.

Concrete is an excellent material for resisting compressive load. Compressive strength is determined by carrying out compressive strength test on cubes of size 150mmX150mmX150mm are casted for the testing of compressive strength. Compressive strength is performed at the age of 7days and 28days. Compressive strength of concrete=P/A. In geopolymer concrete, the compressive strength of concrete increase with increase in concentration of sodium hydroxide solution in terms of molarity. Better compressive strength properties are exhibited in geopolymer concrete.

Split Tensile Strength Test

The split tensile strength test was carried out as per IS 5816:1999. The tensile strength is difficult test to perform and the results are not reliable, in case of direct determination of tension under axial loading, however, there is an indirect method of determining the tensile strength is called split tensile strength.

This test method consists of applying a diametrical force along the length of a cylindrical Geopolymer concrete at a rate that is within a prescribed range until failure.

A cylindrical specimen of standard size 150mm diameter and 300mm height is used for the testing. The specimens were then tested for their splitting tensile strength using universal testing machine at the ages of 7 and 28 days. The split tensile strength of oven cured geopolymer concrete specimens are higher compared to conventional concrete.

Flexural Strength Test

The flexural strength of the geopolymer concrete was carried out as per IS 516:1959, it is a measure of an unreinforced Geopolymer concrete beam to resist failure in bending. The standard beam size of specimens 150x150x700mm is used for the determination of flexural strength of Geopolymer concrete. Then the beam specimen is subjected to the flexural strength test using universal testing machine (UTM) at the ages of 7 and 28 days of curing. The flexural strength of oven cured geopolymer concrete specimens are higher compared to conventional concrete.

Durability properties of Geopolymer concrete

The durability properties of geoplymer concrete is studied by the exposure of geopolymer concrete to acids and sulphates, and it is found that geopolymer concrete shows strong resistance to acids and sulphates compared to conventional concrete, when exposed to several days of time like 28days, 45days, 75days, 90days.

V. CONCLUSION:

- GPC specimens cured artificially in ovens at temperature of 60^{O}C showed more resistance to

Compression, tension and flexure compared to sunlight cured GPCspecimens.

- Even though the combination of fly ash and GGBS (72.5% + 27.5%) is sunlight cured, it showed more strength than that of OPC specimen after 28 days of curing.
- Also oven cured GPC specimens showed more resistance to compression, tension and flexure comparedto OPCC specimens at 7 days and 28 days of curing.
- Oven cured GPC specimens will attain rapid strength gain (more than 90%) at 7 days of curing compared to OPCC specimens at same duration of curing.
- For the addition of steel fibre for 0.25% to 1%, there willbe increase in compressive strength, tensile strength and flexural strength.
- With the addition of steel fibre, the percentage increase in split tensile strength is more compared to compressive strength and flexural strength.
- The strength reduction of geopolymer concrete is less when exposed to both acids and sulphates and the strength reduction in OPC concrete is more when exposed to both acids and sulphates.
- The sunlight cured specimens showed less resistance to acid and sulphate attack compared to oven cured specimens.
- The concentration of acid exposed also affects the strength and the strength decreases as the increase in the concentration of acids.
- The water absorption for normal concrete is more compared to geopolymer concrete.
- High calcium fly ash based concrete showed less water absorption compared to fly ash based and OPC based concrete.

REFERENCES

[1] A Chithambar Ganesh, K Rajesh Kumar, M Vinod Kumar, Vyshnavi, R Vandhiyan, N Gurumoorthy and S Sivakumar (2020). “Durability study on the Hybrid Fiber reinforced Geopolymer concrete made of M-sand under ambient curing”, IOP Conference series: Material Science & Engineering 2020.

[2] Ajay Kumar Singh (2016). “Strength and Durability Testof Fly Ash and GGBS Based Geopolymer Concrete”, International Journal of Engineering Research and Application. ISSN:2248-9622 , Vol.6, Issue 8,(Part-1), August 2016.

[3] Anwar Hosan (2016). "Compressive behavior of sodium and potassium activators synthetized fly ash geopolymer at elevated temperatures: A comparative study", Journal of Building Engineering 8 (2016) 123–130.

[4] D Jayashree, G Rekha (2018). “Experimental study on characteristics of geopolymer concrete with alkaline solution of varying molarity”.

[5] Dilip Srinivas (2017). “Feasibility Analysis of use of Bagasse Ash for the Production of Geo Polymer Concrete”, International Journal of Engineering Research & Technology (IJERT) ISSN: 2278-0181, Vol. 6 Issue 05, May – 2017. Erni Setyowati (2014). “Eco- Building Material of Styrofoam Waste and SugarIndustry Fly-ash Based on Nano-Technology”, Procedia Environmental Sciences 20 (2014) 245 – 253.

[6] Ganesan lavanya and Josephraj Jegan(2016). “Experimental study on durability of high calcium fly ash based geopolymer concrete”.

[7] Kolli Ramujee (2014). “Development of Low Calcium Flyash Based Geopolymer Concrete”, IACSIT International Journal of Engineering and Technology, Vol. 6, No. 1, February 2014.

[8] Kolli Ramujee (2018). “Engineering properties of fly ash based geopolmer concrete”, journel of standard engineering, vol. 45, No. 4, February 2014.

[9] L.Krishnan (2013). “Geopolymer Concrete An Eco- Friendly Construction Material”, IJRET: International Journal of Research in Engineering and Technology Volume: 03 Special Issue: 11 | NCAMESHE – 2014.

[10] N S Kumarvel, P Girija and B Anandhakumar (2015), “Experimental study on durability performance of various grade of geopolymer concrete to resistance of acid and salt”.

[11] P. Priya Rachel & Dr. P. Partheeb (2013). “Durability study of Low Calcium Flyash Based GeopolymerConcrete”, Indian Journal of Applied Research Volume: 03|Issue:6|June 2013|ISSN-2249-555X.

[12] R Manickavasagam and G Mohan Kumar(2017). “Durability studies on the high calcium flyash based GPC”, International journel of engineering, science and technology, vol. 9, No.4, 2017.

[13] Sandeep L.Hake| P.R.Awasarmal| R.M.Damgir. “Durability study on Fly ash Based Geopolymer Concrete for Acidic Environment”, Global Journal of Material Science & Engineering, June 17 2019.

[14] Sujay Chetan Nanavati (2017). "A Review on Fly Ash- based Geopolymer Concrete", IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)Volume 14, Issue 4 Ver. VII (Jul. - Aug. 2017), PP 12- 16.
[15] Tony Suman Kanth D (2015). "Hardened Properties of Bagasse Ash GPC and Rice-husk Ash GPC", International Journal of Innovative Research in Science, Engineering and Technology Vol. 4, Issue 12, December 2015.
[16] V Bhikshma and T Naveenkumar(2014). "Mechanical properties of flyash based geopolymer concrete with addition of GGBS".
[17] U.R.Kawade (2014). "Fly Ash-Based Geopolymer Concrete", International Journal of Innovative Research in Science, Engineering and Technology Volume 3, Special Issue 4, April 2014.