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FLOW PROPERTIES AND STRENGTH BEHAVIOUR OF MASONRY MORTAR INCORPORATING HIGH VOLUME FLY ASH

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ABSTRACT: Masonry mortar is one of the most widely used building materials in construction as nearly all the walls made with bricks are finished with mortar. Masonry works with mortar are generally made with cement, sand and water. In this study, mortar mixes were made by replacing the masonry cement with up to 50% of fly ash at an incremental rate of 10%. Six mortar mixes with 1:4 volumetric cement-to-aggregate ratios using natural sand were made and tested for flow and strength properties. The results obtained from the tests showed that the masonry mortars manufactured with fly ash are better off as compared to the mix without any ash. In terms of flow, it was found that the addition of fly ash increased the flow, particularly when the replacement levels were above 40%. Mortar with high volume fly ash has also shown to attain a comparable strength with that of the control mix. Considering the better workability and acceptable strength properties, the results have demonstrated that high volume replacement of fly ash is a viable alternative for producing environmental friendly masonry mortar.

Keywords: Masonry mortar; High volume fly ash; Flow; Strength

1. INTRODUCTION

Masonry works are the combination of multiple building elements such as bricks which are combined with the use of bonding agent i.e. mortar. Beside the aesthetic purpose, mortar has the function to protect the interior structure from the penetration of air, water or chemical elements into a masonry assembly. The use of mortar in construction works has been the fundamental of ancient civilization where the mixtures were simply prepared using the combination of lime, sand and water. Mortars based lime was substituted by the invention of Portland cement in the 19th century [1]. This is mainly due to the improved mortar properties that Portland cement can provide. Some basic mortar properties are, however, required to ensure the application of mortar is acceptable. For example, the mortar should be plastic enough to be mixed and placed.

It is also important that the compressive strength of mortar is not overemphasized as a stronger mortar might not be required for construction or necessarily better for the masonry unit. The use of high cement content in masonry mortar is not necessarily good as it will increase the risk of efflorescence and also risk of cracking [2-5]. However, the utilization of masonry cement in manufacturing masonry mortar is now widely practiced because it can deliver better plastic consistency and water retentively providing higher workability with minimum cracks. Compared to mortar made with Portland cement, the mortar made with masonry cement often able to give a good flow, low shrinkage and satisfactory strength [6,7]. The improved fresh and hardened properties of masonry cement mortar over the Portland cement mortar are the result of the addition of additives such as air entraining agent and the lower clinker content. Generally, masonry cement mortar has lower compressive strength compared to mortar with Portland cement; however, the bond and compressive strength are more than what is actually required in the real masonry applications. Masonry mortar generally has low cementitious binder as the result of large quantity of limestone used [8].

Fly ash is a by-product of coal combustion from coal fired power plants which is widely used as a supplementary cementing material in both developed and developing countries with numerous advantages. However, it is still rare in the masonry works as partial cement replacement since it is often difficult to achieve desired mortar properties without sacrificing certain fresh or hardened state properties such as early strength [9,10]. Rajamane and Sabitha [11] found that when fly ash is used as cement replacement material it reduces the strength of the mortar. On the other hand, Chindaprasirt [12] observed sufficient strength development to occur in cement mortar replaced by 20-40% fly ash.

Masonry cement generally contains less clinker compared to ordinary Portland cement (OPC). In OPC mortar, a higher amount of hydraulic cement is available to react with water immediately. In contrast, fly ash mixes, are pozzolanic and by themselves are not cement; they contain silica (and alumina) in a reactive form [13]. As a general rule the masonry cement is more environmental friendly as it contains lower amount of clinker that uses less energy to manufacture.

The high volume concept was first introduced by CANMET in 1980s, where cement content was replaced by at least 50% of fly ash. The development of the project was to reduce the CO_2 from the production of clinker of cement, to reduce consumption of natural raw materials such as limestone and also to recycle ash that was generated from the coal fired power plant [14,15]. However, when fly ash is incorporated in large amount in masonry cement, the effective cement in the mortar somehow gets diluted. This limits a high level replacement of masonry cement with substitute materials. Nevertheless, similar to OPC, the hydration of masonry cement still releases $Ca(OH)_2$ which reacts with fly ash to form additional strength giving calcium silicate hydrate.

Over the decades numerous investigations has been conducted on the utilization of high volume fly ash in concrete, although research work on the use of high volume fly ash in mortar are not many. It is believed that the use of fly ash in cementitious material such as masonry cement mortar will not only improve mechanical strength but will also provide resistance to physical and chemical weathering [16-18]. Therefore, the use of fly ash should not be limited to concrete work alone; its use in masonry mortar should be considered as well. Considering the availability and potential benefit of the ash, an attempt was made to study the effect of high volume fly ash on the flow properties and strength behavior of masonry mortar.

2. MATERIALS AND EXPERIMENTAL DETAILS

2.1 Materials and Mix Proportions

The masonry cement used in the mortar mixture was obtained from a commercially available source and the fly ash was obtained from Jimah coal fired power plant which is located at Selangor, Malaysia. The masonry cement has a high Blaine fineness value of 4413 cm^2/g and this is usually contributed by the fine limestone used in it. The Blaine fineness of the ash was 3605 cm^2/g. The masonry cement used in this study is graded as MC 12.5 according to BS EN 413-1:2011 [19]. This grade of 12.5 suggests that the masonry cement has a minimum Portland cement clinker of 40% and the compressive strength between 12.5 MPa to 32.5 MPa when tested according to BS EN 196-1 [20]. The chemical compositions and physical properties of masonry cement and fly ash are given in Table 1 and the scanning electron micrograph (SEM) of the fly ash is shown in Fig. 1.

Table 1 reveals that the masonry cement contains high amount of calcium oxide (CaO) like that of typical Portland cement. This is due to the fact that masonry cement is often manufactured with high amount of limestone powder as clinker replacement. Meanwhile, fly ash is rich in silicon dioxide (SiO_2) and the total of SiO_2, Al_2O_3 and Fe_2O_3 of this fly ash is greater than 70%, which fulfils the chemical composition requirement of Class F fly ash as per ASTM C618 [21]. The loss on ignition (LOI) of masonry cement was at 16.20%, while that of the fly ash was only 0.59%. The sand used in this study was natural sand which fulfills the requirement of ASTM C144 [22]. Throughout the study municipal supplied tap water was used for mixing and curing of the mortar.

According to ASTM C270 [6] masonry mortars are classified into 4 types: these are type M, S, N and O. The mortar prepared and tested in this study fulfils the requirement by having the masonry cement to sand ratio of 1:3. The ratio of binder to sand was kept constant, and the masonry cement was replaced with fly ash at the regular interval of 10%, until it reaches 50%.

Table 1. Chemical composition and physical properties of masonry cement and fly ash.

Elements	Chemical Symbols	Masonry Cement	Fly Ash
Silicon dioxide	SiO_2	11.52	49.97
Aluminium oxide	Al_2O_3	4.19	28.36
Ferric oxide	Fe_2O_3	2.58	7.04
Calcium oxide	CaO	60.98	5.17
Magnesium oxide	MgO	2.34	2.07
Sulphur trioxide	SO_3	2.19	0.46
Sodium oxide	Na_2O	0.19	2.11
Potassium oxide	K_2O	0.91	1.50
Blaine Fineness, cm^2/g		4413	3605
LOI, %		16.20	0.59

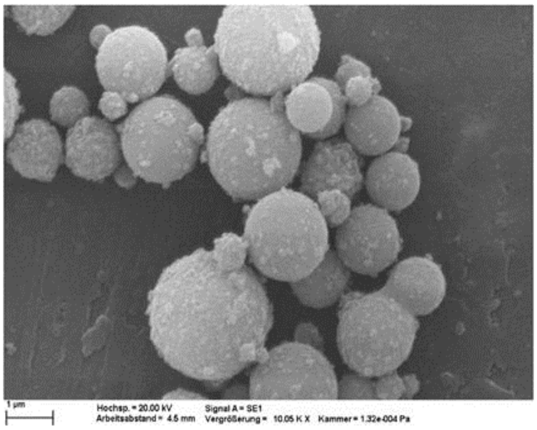


Fig. 1. Scanning electron micrograph (SEM) of fly ash.

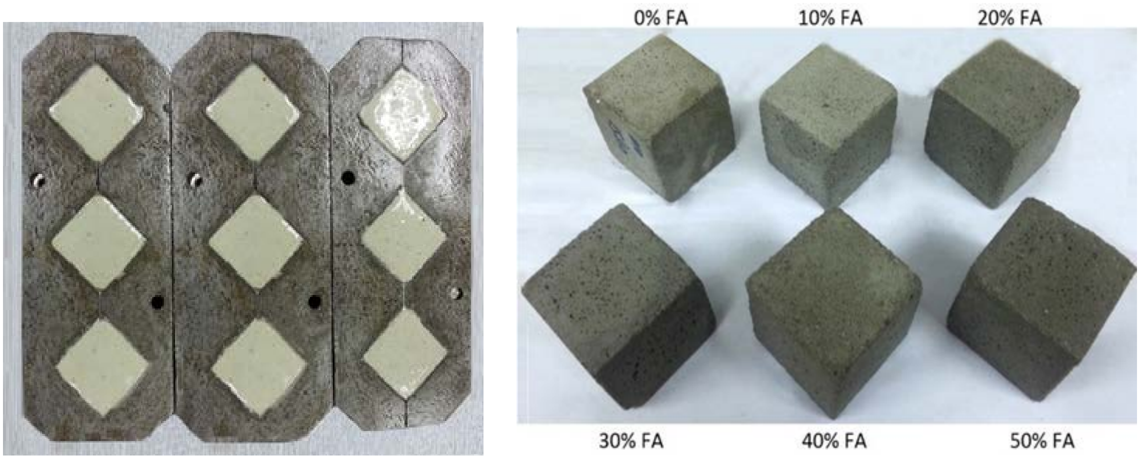
2.2 Experimental Program

Masonry mortars were mixed together using the laboratory Hobart mixer. The sand and the binders were first mixed for about 2 minutes and then water was added and mixed for additional 5 minutes at low speed, and 1 minute at high speed. The mixing of the mortar was first started with the control mortar (% fly ash) to obtain a flow of 110% ± 5%. Sufficient amount of water was added to the mix to achieve this required flow. Subsequent mixes with fly ash employed the same quantity of water. Immediately after mixing, the mortar was removed from the bowl, placed in a layer of about 25 mm in thickness in the mold and was tamped for 20 times.

The mold was then filled with additional mortar and similar tamping was followed. When the mold was full, the excess amount of mortar on the mold was removed and leveled. The test was carried out according to ASTM C1437 [23] where the flow table was dropped 25 times in 15 seconds. The set-up of the drop test is illustrated in Fig. 2.

The compressive strength tests were performed at different curing periods of 7, 28 and 90 days using 50 mm cube specimens (Fig. 3). For each mix proportion, the number of specimens made and tested was three. After 24 hours of casting, the cubes were removed from the mould and water cured at 27 ± 2°C until the test age. The compressive strength test was carried out (Fig. 4) following the method stipulated in ASTM 109 [24].

Fig. 2. Set-up of the flow table test.



(a) (b)

Fig. 3. (a) Casting of mortar mixes in the mould (b) Mortar cubes with different amount of fly ash.

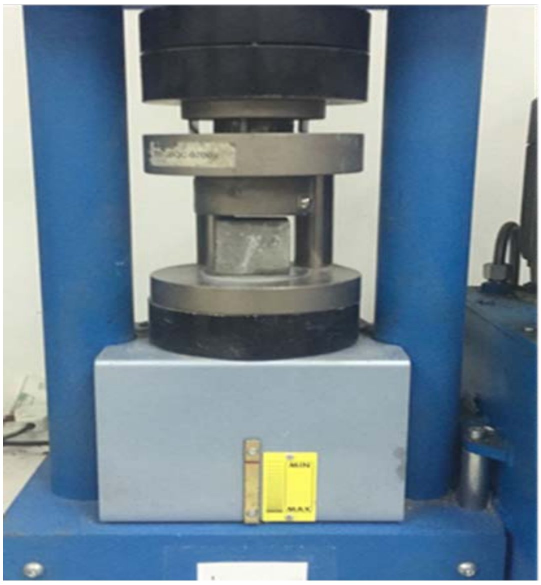


Fig. 4. Compressive strength test.

3. RESULTS AND DISCUSSION

3.1 Flow Properties of Mortar

The flow value of the all the six mixes are graphically shown in Fig. 5. The result obtained shows that with the increase in the fly ash content, the flow of the masonry mortar also increased. It can further be seen that the flow of the mortar increased significantly after the replacement level exceeded 30%. The results obtained in this study are in agreement with the research findings of general concrete and mortar [25-28]. The use of fly ash can, therefore, be a potential way to increase workability of mortar which is beneficial to masonry works where applying and leveling of mortar is easier with better plastic consistency. A flow comparison showing the smooth and plastic consistency of mortar with fly ash is illustrated in Fig. 6.

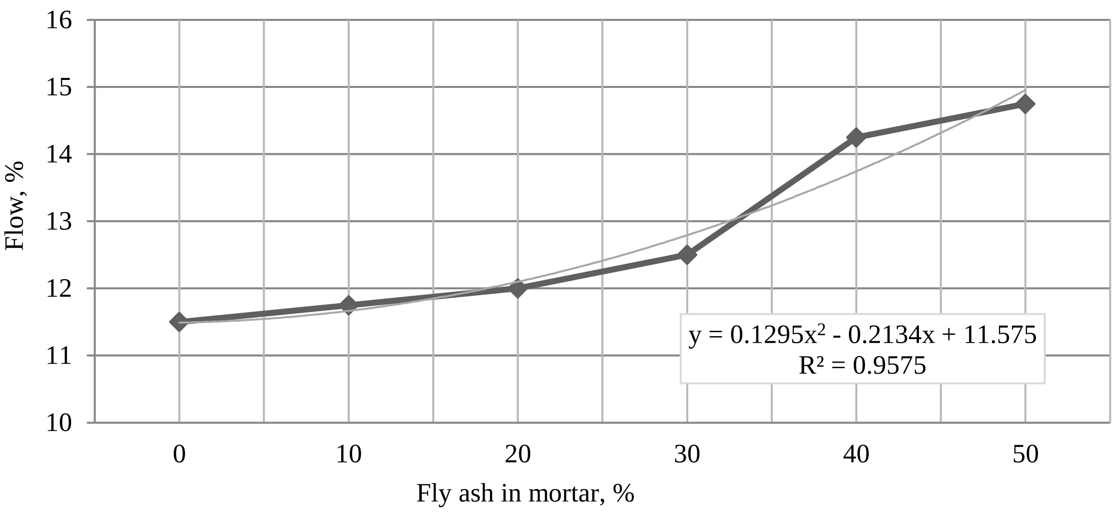


Fig. 5. Flow of masonry mortar containing various amount of fly ash.

(a) Mortar with 0% fly ash

(b) Mortar with 50% fly ash

Fig. 6 Flow comparison between plain mortar (a) and high volume fly ash mortar (b).

3.2 Compressive Strength of Mortar

The compressive strength development of masonry mortar containing various levels of fly ash is presented in Fig. 7. As expected, at early age, the compressive strength of the mortar decreases with the increase amount of fly ash. The decrease in the 1 day strength of mortar mixes are proportionate to the fly ash content, where strength of the mortar with 10, 20, 30, 40 and 50% fly ash was lower by 0.4, 1.2, 1.8, 2.4 and 2.8 MPa respectively. Like that in concrete materials [29-31], this behavior changed with curing time. At the age of 7 days, for example, it is found that the masonry mortar containing 10% fly ash gained almost the same compressive strength as compared to the plain mortar. At 28 days of curing, however, mortar containing 10, 20, 30 and 40% of fly ash exceeded the compressive strength of the plain mortar (11.2 MPa) having 12.0, 13.4, 13.2 and 12.2 MPa respectively. At the age of 90 days, mortar mix containing 50% fly ash achieved 16.2 MPa while the plain mortar at the same time gained only 13.0 MPa. This indicates that the compressive strength development of mortar with fly ash requires longer curing time as compared to plain mortar without any ash.

It is interesting to note that fly ash mortar catches up strength rather fast compared to fly ash concrete mixes where high volume fly ash often needs more than 28 days to acquire strength close to the plain concrete one. The continued increase in strength has been attributed to the pozzolanic behaviour of the ash, which endures to react with the cement to produce calcium silicate hydrate in presence of water [32].

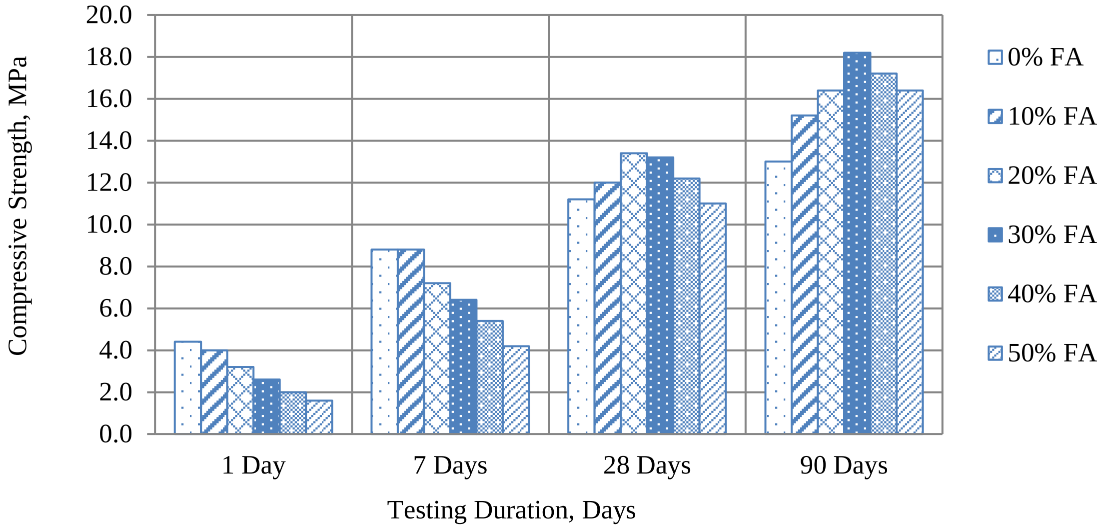


Fig. 7. Strength development of mortar cubes containing various amount of fly ash.

4. CONCLUSIONS

In this study masonry mortar incorporating high volume fly ash was made and tested for flow and strength behavior. The results obtained and the observation made indicate that the use of fly ash in making masonry mortar is highly promising. The high volume fly ash not only improved the flow properties of the mortar, but also increased compressive strength. Although there might be an increased concern over the reduction of air content and higher setting time, these properties can easily be achieved with the inclusion of chemical additives. The application of high volume fly ash, therefore, appears to be advantageous in masonry works considering technical, environmental and economic benefits.

5. REFERENCES

[1] Davey N, “History of Building Materials”, Phoenix House, London, 1961, pp. 97-127.
[2] Das UK, Bhardwaj BB, Choudhury B, Sapkota G, “Effect of gradation of fine aggregate on development of hairline cracks in wall plaster”, Indian J. of Applied Research, Vol. 3, 2013, pp.222-223.
[3] Awal ASMA, “Failure mechanism of prepacked concrete”, J. of Structural Engineering, ASCE, Vol.114, No.3, 1988, pp.727-732.
[4] Awal ASMA, “Creep recovery of prepacked aggregate concrete”, J. of Materials in Civil Engineering, ASCE, Vol.4, No.3, 1992, pp.320-325.
[5] Hossain MZ and Awal ASMA, “Experimental validation of a theoretical model for flexural modulus of elasticity of thin cement composite, Construction and Building Materials, Vol. 25, No.3, 2011, pp.1460-1465.

[6] ASTM C270, Standard specification for mortar for unit masonry. ASTM International, 2014.

[7] Awal ASMA, Mohammadhosseini H and Hossain MZ, "Strength, modulus of elasticity and shrinkage behaviour of concrete containing waste carpet fiber", Int. J. of GEOMATE, Vol.9, No.1, 2015, pp.1441-1446.

[8] Wills MH Jr, U.S. Patent No. 4,268,316. Washington, DC: U.S. Patent and Trademark Office, 1981.

[9] Guo X, Shi H and Dick WA, "Compressive strength and microstructural characteristics of Class C fly ash geopolymer". Cem. and Concr Composites, Vol.32 No.2, 2010, pp. 142-147.

[10] Alam JB, Awal ASMA, Alam MJB, Rahman MM, Rahman MS, Banik BK and Islam S, "Fly-ash as admixture in manufacturing of cement - a case study", Malaysian J. of Science, Vol.27, No.1, pp. 2008, pp.1-6.

[11] Rajamane NP and Sabitha D, "Effect of fly ash and silica fume on alkalinity of cement mortar". Indian Concrete J., 79(3), 2005, pp.43-48.

[12] Chindaprasirt P, Buapa N and Cao HT, "Mixed cement containing fly ash for masonry and plastering Work". Construction and Building Materials, Vol.19, No.8, 2005, pp. 612-618.

[13] Balakrishnan B and Awal ASMA, "Mechanical properties and thermal resistance of high volume fly ash concrete for energy efficiency in building construction" Key Engineering Materials, Vol. 678, 2016, pp.99-108.

[14] Bouzoubaa N, Zhang MH and Malhotra VM, "Mechanical properties and durability of concrete made with high-volume fly ash blended cements using a coarse fly ash". Cement and Concrete Research, Vol.31, No.3, 2001, pp.1393-1402.

[15] Balakrishnan B and Awal ASMA, "Durability properties of concrete containing high volume Malaysian fly ash". International J. of Research in Engineering and Technology, Vol.3, No.4, 2014. pp. 529-533.

[16] Malhotra VM, "Durability of concrete incorporating high-volume of low-calcium (ASTM Class F) fly ash", Cement and Concrete Composites, Vol.12, No.4, 1990, pp.271-277.

[17] Shehu IA and Awal ASMA, "Mechanical properties of concrete incorporating high volume palm oil fuel ash", Advanced Materials Research, Vol.599, 2012, pp.537-540.

[18] Awal ASMA and Shehu IA, "Performance evaluation of concrete containing high volume palm oil fuel ash exposed to elevated temperature", Construction and Building Materials, Vol. 76, 2015, pp.214-220.

[19] BS EN 413-1, Masonry cement. Composition, specifications and conformity Criteria. CEN, Brussels, 2011.

[20] BS EN 196-1, Methods of testing cement. Determination of strength. CEN,Brussels, 2005.

[21] ASTM C618, Standard specification for coal fly ash and raw or calcined natural pozzolan for use in concrete. ASTM International, 2015.

[22] ASTM C144, Standard specification for aggregate for masonry mortar. ASTM International, 2011.

[23] ASTM C1437, Standard test method for flow of hydraulic cement mortar. ASTM International, 2015.

[24] ASTM C109, Standard test method for compressive strength of hydraulic cement mortars (Using 2-In. or [50-mm] Cube Specimens). ASTM International, 2016.

[25] Shrivastava Y and Bajaj K, "Performance of fly ash and high volume fly ash concrete in pavement design". IPCSI, Vol. 28, 2012, pp. 188-192.

[26] Yijin Y, Shiqiong Z, Jian Y and Yingli G, "The effect of fly ash on the fluidity of cement paste, mortar, and concrete". In Int. Workshop on Sustainable Development and Concrete Technology, Beijing, 2004, pp. 339-345.

[27] Lachemi M, Hossain KMA, Pate R, Shehata M and Bouzoubaa N, "Influence of paste/mortar rheology on the flow characteristics of high-volume fly ash self-consolidated concrete". Magazine of Concrete Research, Vol.59, Issue7, 2007, pp. 517-528.

[28] Raut AN and Gomez CF, "Thermal and mechanical performance of oil palm fiber reinforced mortar utilizing palm oil fly ash as a complementary binder", Construction and Building Materials, Nov 2016.

[29] Barbhuiya SA, Gbagbo JK, Russell MI and Basheer PAM, "Properties of fly ash concrete modified with hydrated lime and silica fume". Construction and Building Materials, Vol. 23, No.10, 2009, pp.3233–3239.

[30] Li G and Zhao X, "Properties of concrete incorporating fly ash and ground granulated blast furnace slag". Cement and Concrete Composites, Vol. 25, No.3, 2003, pp.293-299.

[31] Awal ASMA, Kadir MAA and Hossain MZ, "Some aspects of physical and mechanical properties of sawdust concrete", Int. J. of GEOMATE,Vol.10,No.21,2016,pp.1918-1923.

[32] Johari MAM, Brooks JJ, Kabir S and Rivard P, "Influence of supplementary cementitious materials on engineering properties of high strength concrete". Construction and Building Materials, Vol. 25, No.5, 2011, pp.639–2648.