HEFAT2012
9th International Conference on Heat Transfer, Fluid Mechanics and Thermodynamics
16 – 18 July 2012
Malta

EVALUATION OF TYPE C FLY ASH IN THE PRODUCTION OF COMPOSITE MATERIAL

Argunhan Z.* , Yıldız T., Çakmak G., Yücel H. L. and Yıldız C.

*Author for correspondence
Batman University, Energy Systems Engineering Department, Batman, Turkey
E-mail: zeki.argunhan@batman.edu.tr

ABSTRACT

In this study, the availability as a new composite material of the class C fly ashes which have negative effects on environment was investigated. First of all, the properties of fly ash and polypropylene have been identified. By making use of the obtained results, the availability of fly ash and polypropylene materials was investigated in production of a new composite material. For this purpose, by using type C fly ash of thermal power plants in mass ratios of 10% - 60%, a new composite material was produced. To determine mechanical and physical properties of the produced composite samples, thermal conductivity, compressive strength, water absorption capacity, and abrasive loss were performed. From the results, it was witnessed that both environmental problems can be reduced and economical profit can be achieved by means of energy saving.

INTRODUCTION

Solid waste management is becoming a challenging problem for major cities worldwide. Similarly, the fly ash and waste plastic materials cause environmental pollution.

With this aim, utilization of fly ash as a resource has been studied for decades in many areas such as in valuable element extraction, in environmental engineering, in building products, in plastic industry, in ceramic products.

Fly ash is a waste material resulting from coal being burned in thermal power plants. Fly ash is one of the residues generated in the combustion of coal. Total amount of fly ash produced at coal-fired power plants is about 450 million tons/year in the world. The amount of fly ash produced in Turkey is about 15 billion tons/year in 11 coal-fired power plants.

Plastics are used in our daily lives in a number of applications. A lot of plastic products are often discarded after a single use. During last decades, the consumption of plastics with the great population increase worldwide was increased. The plastic wastes create vast waste each year to the creating a serious environmental problem.

The fly ash is also used in the manufacturing of brick, fly ash mineral-based polymer composites ceramic tableware and art ware [1-3].

Van Deventer et al. [4] have carried out a series of tests to produce geopolymers from fly ash. Swamy et al[5] developed many mixes of normal and lightweight concretes containing 30% of fly ash by weight of cement which provided adequate early compressive strength compared to the concrete without fly ash. Naik and Name [6] provided concrete mixes containing large quantities of fly ash which achieved compressive strengths.

Berry et al. [7] suggested that coarse fly ash exhibited low pozzolanic activity since it contained a high proportion of crystalline phases.

There have been reports on the utilization of these wastes for making cementations binders and building products. Li et al. [8] conducted laboratory tests to evaluate the use of RPM blended with fly ash in a base course. Mirza et al. [9] noticed the improvement of stability and the reduction of drying shrinkage in cement based grouts with fly ash. Glukhovsky et al. [10] noted the superior properties of his new materials compared with existing cement-based materials. Fly ash is also used as an additive in the production of briquettes [11].

The use of fly ash in plastic composites has shown promise [12], as has application in metal composites, in particular aluminum [13].

NOMENCLATURE

k	[W/mK]	Thermal conductivity
M_D	[g]	Mass after drying
M_F	[g]	Mass before test
M_L	[g]	Mass after test
M_D	[g]	Mass after drying
M_W	[g]	Wet mass after water absorption
W_A	[%]	Rate of water absorption (%)
W_{AL}	[%]	Abrasion loss (%)

Benavidez et al. [14] studied the densification of mixtures of fly ash and bottom ash in different ratios. It was found that the powders with high fly ash content exhibited higher packing density and eventually higher sintered density. Xu et al. [15] studied the effect of fly ash addition on the properties of fired bricks.

Similarly some studies [16]; have showed that it is indeed possible to use plastic waste in concretes or mortars.

These research works reported in plastic composite area include projects on structural and functional evaluation. Plastic waste represents a raw material for the development of thermoplastic composites [17].

Yam et al. [18] has evaluated the mechanical properties of woodfibre–waste plastic composites.

In this study, possible use of C type -Afşin ElbistanThermal Power Plant fly ash and propylene wastes in a new composite material was investigated. For this purpose, nine kinds of composite materials containing 10%-90% Afşin Elbistan thermal power plant fly ash were produced. Thermal conductivity, compressive strength, water absorption and abrasion tests were applied to investigate the mechanical and physical properties of the fabricated composite material specimens. In this application, these two waste materials can be utilized together, both to eliminate environmental problems and to get economical gains by saving energy.

Class C fly ash

Fly ashes may be sub-divided into two categories, according to their origin (ASTM) [19]:

Class F : Fly ash normally produced by burning anthracite or bituminous coal which meets the requirements applicable to this class.

Class C : Fly ash normally produced by burning lignite or sub-bituminous coal which meets the requirements applicable to this class. Class C fly ash possesses some cementations properties. Some Class C fly ashes may have lime contents in excess of 10 % [20].

Physical properties of fly ash mainly depend on the type of coal burned and the burning conditions. Class F fly ash is generally produced from burning high rank (containing high carbon content) coals such as anthracite and bituminous coals, whereas, Class C fly ash is produced from low rank coals.

Its physical and chemical properties depend exclusively on the quality of coal used and on technological conditions of burning [21].

Physical and compositional properties of the fly ashes are summarized in Table 1 along with typical physical properties of Class C and F fly ashes.

While Class F fly ash is highly pozzolanic, meaning that it reacts with excess lime generated in the hydration of portland cement, Class C fly ash is pozzolanic and also can be self-cementing. ASTM C618 requires that Class F fly ash contain at least 70% pozzolanic compounds (silica oxide, alumina oxide, and iron oxide), while Class C fly ashes have between 50% and 70% of these compounds.

Table 1. Chemical Composition and Index Properties of Fly Ashes [22].

Percent of composition	Typical Class C	Typical Class F
CaO	24.3	8.7
SiO2	39.9	54.9
Al2O3	16.7	25.8
Fe2O3	5.8	6.9
MgO	4.6	1.8
SO3	3.3	0.6
CaO/SiO2 ratio	0.61	0.16
Loss on ignition (%)	6	6
Classification (*ASTM 618*)	C	F

Polypropylene

Polypropylene is a thermoplastic polyolefin that is produced by polymerizing propylene monomer, which is a gaseous byproduct of petroleum refining, in the presence of a catalyst under controlled heat and pressure [23].

Polypropylene, with the chemical formula (C3H6)x (Figure 1), is a thermoplastic polymer used in a wide variety of applications including packaging, plastic parts, laboratory equipment, automotive components etc. Crystallinity property and Young's Modulus of polypropylene is between that of low density polyethylene and high density polyethylene. It is less tough but also less brittle than high density polyethylene, this allows polypropylene to be used as an engineering plastic. Resistances to fatigue, high melting point (130-168 °C) and relatively low cost are the other superior properties of polypropylene.

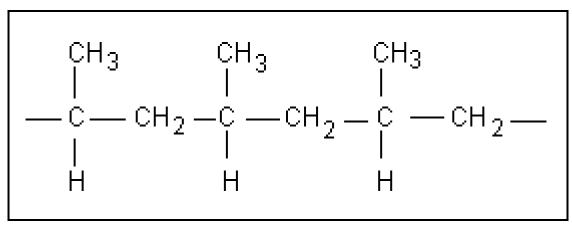

Figure 1. Molecular structure of polypropylene chain.

Due to its non-polar nature, polypropylene has high resistance to most solvents and chemicals and also good resistance to moisture. Non-polar structure also makes PP hydrophobic and makes polar clay minerals and layers difficult to disperse in it. It's highly crystalline nature provides high tensile strength, stiffness and surface hardness to polypropylene.

Polypropylene is a lightweight plastic that is rigid and tough. Combined with its low cost, polypropylene is used in a wide variety of applications. The polypropylene has a semi-crystalline structure that offers good mechanical properties such as stiffness and tensile strength. When combines with different fillers such as clay, talc, calcium and glass, the mechanical properties of polypropylene can be dramatically enhanced. The addition of 30% short fiber glass reinforcement increases tensile strength and doubles the impact resistance [24]. Table 2 furnishes some mechanical properties of polypropylene homopolymer.

Polypropylene is useful a wide range of applications because of its properties.

- Fairly low physical properties
- Fairly low heat resistance
- Excellent chemical resistance
- Translucent to opaque
- Low price
- Easy to process

Table 2. Selective properties of polypropylene

	Property
Tensile strength, MPa	36
Elongation at break. %	350
Flexural modulus, MPa	1310
Brittle temperature, ^{0}C	+15
Softening point,^{0}C	145-150
Hardness, (R-scale)	95
Impact strength,kJ/m^2	24.5
MFI, g/10 min	8.7 (2.16 kg/230 ^{0}C)

Polypropylene is transformed into useful products by a wide variety of processes, which has been, together with a suitable cost/performance balance, a major factor in its commercial success. Figure 2 shows the breakdown of global sales among the major processes. The ease of molding and the attractive strength, stiffness, and high use temperatures of articles molded of polypropylene have made injection molding the largest consumer of polypropylene among the processes used.

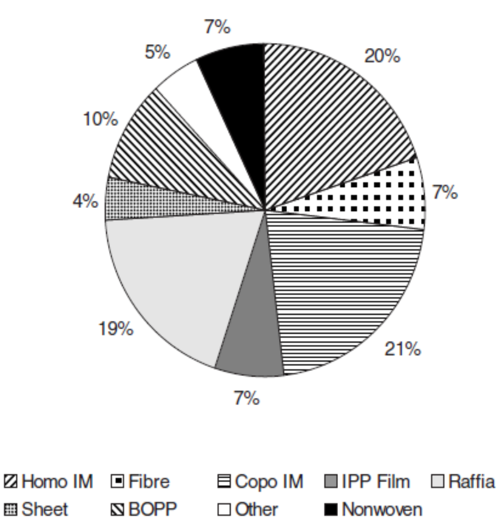

Figure 2. Breakdown of polypropylene demand by end-use [25].

A unique aspect of the polypropylene processes, compared to the other major plastics, is the use of orientation to develop enhanced properties, principally in fibers and films, constituting nearly one-half of the consumption. None of the other major plastic materials uses orientation to any appreciable extent, except PET, which is considered a major plastic, where orientation is used in fibers, biaxially oriented films, and soda bottles, and nylon, which is oriented into fibers. Lesser but significant quantities of polypropylene are used in unoriented film, sheet, and blow molding.

EXPERIMENTAL

Materials

Fly ash from the Afşin Elbistan Power Plant in Turkey was used in this study. According to ASTMC 618 [19], Fly ash from Afşin Elbistan can be classified as class-C Fly ash because it has an S+A+F higher than 50% and lower than 70%.

In addition, recycled polypropylene was obtained from post consumer plastic products and was used as the matrix material.

This ASTM class 'C' fly ash (as per ASTM-C 618) was found to have different proportions of oxides. The chemical composition of Afsin-Elbistan fly ashes is given in Table 3. In addition major physical properties of these fly ashes are shown in Table 4.

Table 3. Chemical composition of Afsin-Elbistan fly ashes[26].

Element oxide	(%)
SiO2	15.14
Al203	7.54
Fe203	3.30
CaO	23.66
MgO	4.50
K2O	0.28
Na2O	0.57
TiO2	1.03
SO3	13.22
Cd*	8.0
Pb*	79.6
Zn*	79.6
Cu^b	39.8
Cr*	298.4
Ni^b	119.4
Mn*	218.8
LOI	2.31

Table 4 Major physical properties of Afsin-Elbistan fly ashes [26]

pH	12.5
Particle size	65% ≤75 µm
Specific surface area (m2/g)	0.342
Bulk density (g/cm3)	1.05
Specific gravity (g/cm3)	2.70
pH_{ZPC}	7.0
LOI	2.31

Experimental procedure

The fly ash and the recycled polypropylene samples were taken in six ratios. Six groups of mixes of fly ash and polypropylene were produced. The percentage ratios of the weights of fly ash are 10, 20, 30, 40, 50 and 60. They were specified as Table 5.

Table 5. Ratios of the weights of fly ash and polypropylene

Label	**Material (%)**	
	% FA	% PP
AFP10	10	90
AFP20	20	80
AFP30	30	70
AFP40	40	60
AFP50	50	50
AFP60	60	40

The fly ash and the polypropylene were mixed in an internal mixer for 30 min at a temperature of 200°C. The concrete mixes were prepared as homogeneity. For each mixture, these different samples were prepared for measuring mechanical properties, moist, density, the loss in weight and their thermal conductivities.

Tensile tester was used to measure tensile properties. The tensile tests were performed as per TS 699(Model BC100). At least three specimens were tested for each variation in the composition of the composites. The maximum rate of pressure applied for samples was 200 t.

The thermal conductivity coefficient of the samples was carried out for using Hot-Wire instrument as per DIN51046 (Showa Denko). Its sensitive is given as ±5% digit and the measurement range is stated as 0.02-10 W/mK [2].

The samples for water absorption were placed in a water tank at room temperature. The samples after a certain periods were removed from water. The percentage weight gain of the samples was measured. These samples were in an open atmosphere for three days. The rate of water absorption of samples was calculated using the following equation:

$$W_A = [(M_W - M_D) / M_D] \times 100 \qquad (1)$$

On the samples, surface abrasion loss (Bohme) tests are performed using TS 699. For the determination of Bohme abrasion loss was prepared samples in compliance with TS 699. The abrasion losses of the samples were tested. The abrasion loss values are determined following equation.

$$W_{AL} = [(M_F - M_L) / M_F] \times 100 \qquad (2)$$

RESULTS AND DISCUSSION

A typical SEM photo of fly ash and polypropylene samples is shown in Figure 3. The figure showed that the fly ash particles are smoothly encapsulated in polypropylene.

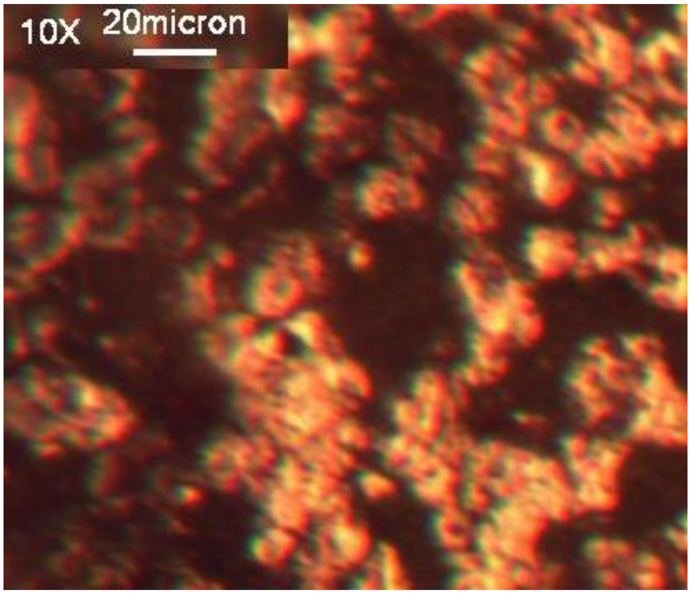

Figure 3. SEM photo of the composite material with polypropylene and 50% of fly ash

The thermal conductivity coefficient (k) is computed by using the average of these five k values and it is shown in Figure 4.

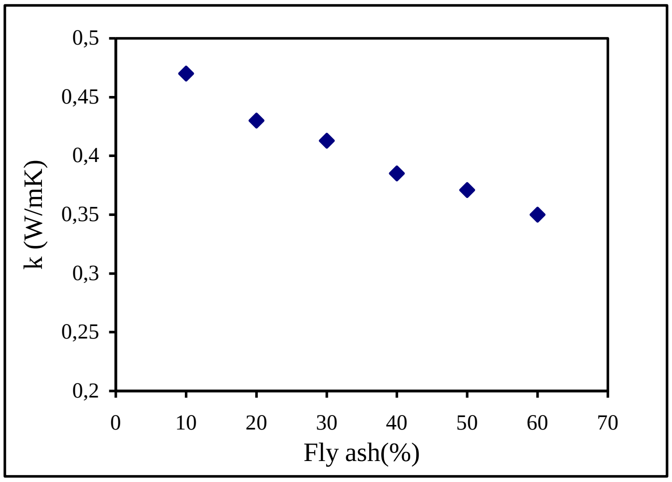

Figure 4. The thermal conductivity coefficient and fly ash relation

This figure demonstrates that the thermal conductivity with increasing fly ash was decreased. The results in Figure 4 indicate that reductions in thermal conductivity are possible by incorporating high volumes of fly ash into polypropylene. The lowest value of the thermal conductivity is obtained for sample with 60% fly ash. This reduction in thermal conductivity is related to the increase of porosity.

The compressive strength values are presented in Figure 5. The compressive strength values are inversely proportionate with the percentages fly ash. The highest compressive strength was measured in the sample with 10% fly ash and 90% polypropylene which was 106 kp/cm^2.

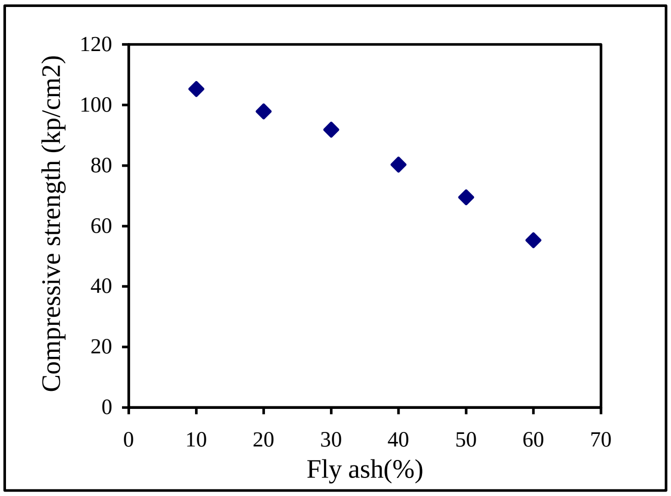

Figure 5. The compressive strength and fly ash relation

The abrasive loss determined for samples shown in Figure 8. The lowest value of the abrasive loss was determinate for sample produced with 10% fly ash. The compressive strength values with the abrasive loss values are shown similar result.

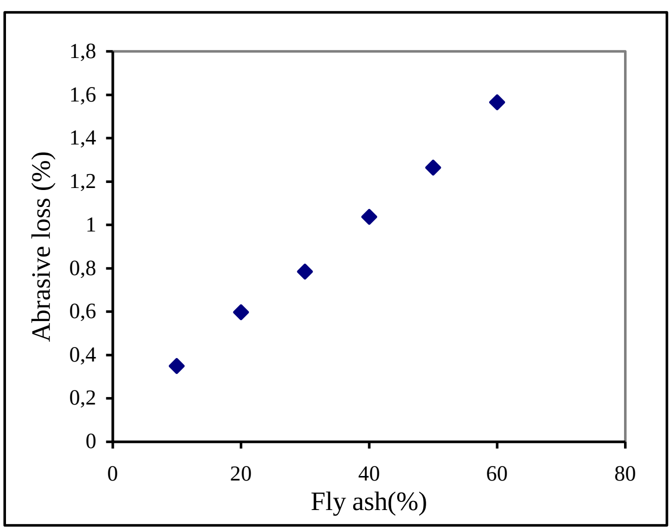

Figure 6. Abrasive loss and fly ash relation

Figure 7 shows the influence of total mass on the water absorption as a function of time. It is shown that increasing the percentage of fly ash leads to the increase of water absorption. The water absorption of the all samples achieved in the limits of TSE.

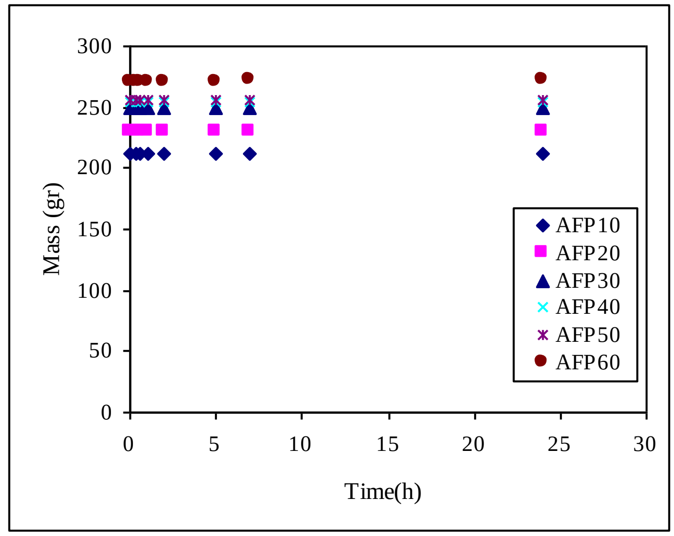

Figure 7. Total mass change on water absorption as depending on time.

CONCLUSION

The aim of this study was to investigate the usability of fly ash and polypropylene as building material. As a result of this experimental study provided the following conclusions.

It was suggested that fly ash could be an alternative filling material for polypropylene. In overall, the mechanical properties of product obtained of the polypropylene were affected positively.

The changes in the thermal properties and the mechanical properties of new material obtained were explained by the differences in the composition and shape of the fly ash particles. It was observed that additive of polypropylene and fly ash increased strength and decreased thermal conductivity coefficient from test results. The minimum thermal conductivity coefficient value was founded for 60% fly ash and 40% polypropylene.

Reducing the thermal conductivity coefficient increases the insulation value provided by the composite, potentially contributing to a reduction in heating and cooling costs for residential and commercial buildings constructed

Wastes are gained to economy and environmental contaminant is decreased owing to usage of polypropylene and fly ash on a new building materials. Since this composite material has low density and thermal conductivity coefficient, it could potentially be used as an alternative lightweight building material.

REFERENCES

[1] Anderson M., A new low-cost PFA brick making process, *International Conference on Ash Technology*, London, 16–22 September, 1984, pp. 569–573.

[2] Wu X., Wastiels J., Faignet S., Bauweraerts P., A composite matrix material based on fly ash, in: A.M. Brandt, V.C. Li, I.H. Marshall (Eds.), in: *Proceedings on International Symposium on Brittle Matrix Composites* 4, IKE and Woodhead Publ, Warsaw, 1994, pp. 437–446.

[3] Mukherji S.K., Machhoya B.B., The utilization on fly-ash in the preparation of ceramic tableware and artware, *Br. Ceram. Trans.* 92 (1), 1993, 6–12.

[4] Van Jaarsveld JGS, Van Deventer JSJ, Lukey GC. The effect of composition and temperature on the properties of fly ash- and kaolinite-based geopolymers. *Chem Eng J*, 89, 2002, pp.63–73.

[5]Swany RN., Ali A. Theodorakopoulos DD., Early strength fly ash concrete for structural applications, *ACI J*, 1983, pp. 414-423.

[6] Naik TR, Ramme BW, High strength concrete containing large quantities of fly ash, *ACI Mater J*, 86, 1989, pp.111-6

[7].Berry EE, Hemmings RT, Largley WS, Carette GG, Beneficiated fly ash: hydration, microstructure and strength development in Portland cement, In: *Proceeding of First International Conference on Fly Ash, Silica Fume*, Slag and Natural Pozzolans in Concrete, SP-114, Detroit, USA, 1989, pp.241-73

[8] Li L. Benson CH, Edil TB, Hatipoglu B, Tastan E. Evaluation of recycled asphalt pavement material stabilized with fly ash. *ASCE Geotechnical Special Publication* 2007, 169 (CD-ROM).

[9] Mirza J et al. Basic rheological and mechanical properties of high-volume fly ash grouts. *Constr Build Mater* 16, 2002, pp.353–63.

[10] Glukhovsky V.D., Rostovskaja G.S., Rumyna G.V., High strength slag-alkaline cements, in: Proceedings of the 7th *International Conference on Chemical Cement Communication,* vol. 3, Paris, France, 1980, pp. 164–168.

[11] Xu L., Guo W., Wang T., and Yang N., Study on fired bricks with replacing clay by fly ash in high volume ratio, *Construction and Building Materials*, vol. 19, no. 3, 2005, pp. 243– 247.

[12] Yıldız, T., Haksever, A., Uçucu kül ve polipropilen atıklarının değişik kombinasyonlarda kompozit malzeme üretiminde değerlendirilmesi, *Termodinamik*, 104,2001, pp. 65-70.

[13] Rohatgi PK, Guo RQ, Keshavram BN., Cast aluminium alloy -fly ash composites. *Key Eng Mater*, 104-107, 1995, pp.283–292.

[14] Benavidez E, Grasselli C, Quaranta N. Densification of ashes from thermal power plant. *Ceram Int*., 29, 2003, pp.61–68.

[15] Xu Lingling, Guo Wei, Wang Tao, Yang Nanru. Study on fired bricks with replacing clay by fly ash in high volume ratio. *Constr Build Mater*, 19, 2005, pp.243–247.

[16]Rebeiz KS, Craft AP. Plastic waste management in construction: technological and institutional issues. *Resour, Conserv Recy*, 15, 1995, pp.245–57.

[17].Adhikary, K.B., Pang, S., Staiger, M.P., Dimensional stability and mechanical behavior of wood–plastic composites based on recycled and virgin highdensity polyethylene (HDPE). *Composites Part* B 39 (5), pp. 807–815, 2008.

[18] Yam KL, Gogoi BK, Lai CC, Selke SE. Composites from compounding wood fibers with recycled high density polyethylene. *Polym Eng Sci*;30(11), 1990, pp. 693–699.

[19].ASTM C 618-85, Standard specifications for fly ash and raw or calcined natural pozzolan for use as mineral admixture in Portland cement concrete. *ASTM.* Philadelphia, USA., 1985.

[20]Weshe, K., Fly Ash in Concrete Properties and Performance Report of Technical Committee 67-FAB. (Use *of Fly Ash in Building Ritem Report 7*, London, New York), 1999, pp. 5-22.

[21]Drazan J, Zelic J.. The effect of fly ash on cement hydratıon in aqueous suspensions. *Ceramics−Silikaty*. 50(2): 2006,pp 98-105.

[22]. Bin-Shafique, S., Edil, T., Benson, C., and Senol, A. “Incorporating a fly ash stabilized layer into pavement design—Case study.” *Geotechnical engineering*, Institution of Civil Engineers, London, Vol. 157, No. GE4, 2004, pp.239–249.

[23].Karian H.G., *Handbook of Polypropylene and Polypropylene Composites*, Marcel Dekker Incorporated, New York, 1999.

[24] Strong A. Brent., *Plastics*, Material and Processing, Prentice Hall, 2000:.

[25] Pasquini N., *Polypropylene Handbook*, 2004

[26] Bayat O., Characterisation of Turkish fly Ashes, *Fuel*, Vol. 77, No. 9/10, 1998, pp. 1059-1066.