Third International Conference on Sustainable Construction Materials and Technologies http://www.claisse.info/Proceedings.htm

Low carbon foot print binders for paving blocks

Eshmaiel Ganjian[1], Ghassan Jalull[2] and Homayoon Sadeghi-Pouya[3]

[1]Reader in Civil Engineering Materials, Department of Civil, Architecture and Building, Faculty of Engineering & Computing, Coventry University, UK, CV1 5FB, E.Ganjian@Coventry.ac.uk

[2]PhD student in Civil, Architecture and Building Department, Faculty of Engineering & Computing, Coventry University, UK, CV1 5FB, and Lecturer in Department of Civil Engineering, Faculty of Engineering, Al Zawiya University, Al Zawiya, Libya, , Jalullg@uni.Coventry.ac.uk

[3]Research Fellow, Department of Civil, Architecture and Building, Faculty of Engineering & Computing, Coventry University, CV1 5FB, H.Sadeghipouya@coventry.ac.uk

ABSTRACT

In the production of conventional paving blocks about 210 kg cement per m^3 are used. It is already common practice to use replacements for part of the cement in concrete but this is restricted by limited availability and high costs. This paper presents the use of waste and by products materials such as basic oxygen slag (BOS), plasterboard gypsum (PG), run of station ash (ROSA), cement bypass dust (BPD) and Ground Granulated Blast furnance Slag (GGBS) to produce paving blocks by mixing in binary and ternary blends. Compressive and splitting tensile strength was measured on paving blocks and cubes specimens. Results confirmed that ROSA up to 35%, BOS up to 70%, BPD up to 10%, GGBS up to 35% and PG up to 5% by weight can replace the Portland cement without negative impacts on their desirable properties in accordance to the BS EN 1338: 2003.

Keywords: Paving blocks, Splitting tensile strength, Compressive strength, GGBS, BOS

INTRODUCTION

Cementitious binders in the form of pre-cast paving blocks are widely used for a wide range of applications including that of exterior landscaping. Such blocks are available in a number of different shapes and colours. The appeal of paving blocks is that they are able to provide a hard surface which is visually attractive and easy to walk upon while at the same time allowing for easy maintenance and having a long life in use. They can therefore be used for the most heavy duty purposes such as car parks, bus terminal and stops, petrol stations, roundabout, Industrial estates, etc. and being able to cope with considerable loads as well as offering resistance to those forces that might shear the surface or otherwise damage it.

Portland cement is the essential material that is used in all paving blocks. However, as is well known the production of every tonne of Portland cement releases approximately 1 tonne of carbon dioxide - a major contributor to the greenhouse gas emissions that are responsible for global warming. Considering the yearly Portland cement production of 1.6 billion tonnes

(Turanli, 2004), the cement industry itself is responsible for about 8% of the total global carbon emissions (Oliver et al, 2012). Since seventies ongoing attempts have been made by researchers to find suitable materials to partially replace Portland cement. A number of these materials, such as pozzolan, limestone and metakaolin occur naturally while others, such as fly ash, slags, silica fume and others are the by-products of industries. (Menéndez, et al. 2002). The recycling of industrial waste or by-products such as steel slag, run of station ash and bottom ash, cement kiln dust, lime kiln dust, municipal incinerated ash is of increasing interest worldwide, due to the high environmental impact of the cement and concrete industries (Bertolini et al, 2004). Harmful effects of concrete on the environment can be reduced by producing durable concrete and effective use of resources. Industrial by-products and solid wastes can be used for this purpose. According to the industrial ecology concept for sustainable development, the by-product of one industry may be a raw material for another industry (Mehta, 2001 and Mehta 2002).

Using more waste materials will decrease their effect on the environment and help to save natural raw materials as well as reducing the overall energy required to produce a cementitious material and thereby reducing the emissions of carbon dioxide (CO_2) (Ganjian et al. 2009). The main beneficiaries of these outcomes will be: (1) The environment will benefit from reduced CO_2 emissions. (2) The concrete producers will benefit from reduced costs. (3) The waste producers will benefit from reduced disposal costs through land-fill diversion.

The aim of this study is to explore the possibility of using a mixture of different waste pozzolans to make paving blocks, and to reduce the percentage of Portland cement in the mixture.

MATERIALS USED:

The Portland cement CEM I was obtained from Castle cement which complies with the specifications as per the BS EN 197-1 - CEM I 52.5 R and Libyan standard 340/97. The average particle size of the OPC used was 25 microns and the maximum particle size of 0.3 mm.

Run-of-station ash used in this study was from Rugby Ash. The average particle size of the ROSA used was 20 microns and the maximum particle size of 500 µm.

The basic oxygen slag has been acquired from the Tata plant at Scunthorpe for this study. In the UK approximately one million tonnes of basic oxygen slag is produced each year with about ten million tonnes of it being stored for weathering so that free lime can hydrate (Ghataora et al., 2004). The average particle size of BOS was 40-60 µm and the maximum particle size of 600 µm.

The Ground Granulated blast furnace slag (GGBS) was obtained from Civil and Marine, a part of Hanson UK. The material was marketed under the BS 6699 standard. The average particle size of the GGBS used was 20 microns and the maximum particle size of 0.1 mm.

BPD from a local cement works, Castle Cement (Heidelberg cement group in Rugby, UK) was obtained for this research. The average size of BPD used was about 10 µm and the maximum particle size of 200 microns.

Crushed plasterboard gypsum waste was supplied by Lafarge plasterboard recycling plant in Bristol and was grind in the laboratory. PG particle size was found to have average size of 300 µm and maximum particle size of 1 mm in diameter.

Chemical Analysis

The chemical analysis of the materials used is shown in Table 1. This was carried out by employing XRF (X-Ray Fluorescence) technique.

Table 1. Chemical composition of material used

Sample oxides	**OPC (%)**	**BOS (%)**	**ROSA (%)**	**PG (%)**	**PBD (%)**	**GGBS (%)**
SiO_2	20.00	11.43	45.91	2.43	21.86	37.28
TiO_2	-	0.39	1.41	0.03	0.29	0.58
Al_2O_3	6.00	1.60	26.51	0.81	3.85	10.79
Fe_2O_3	3.00	28.24	5.23	0.36	2.57	0.43
MnO	-	4.35	0.08	< 0.01	0.02	0.68
MgO	1.50	8.27	2.13	0.40	1.13	8.83
CaO	63.00	41.29	6.88	37.30	53.40	40.12
Na_2O	1.00	0.02	0.61	0.03	0.41	0.27
K_2O	1.00	0.02	1.35	0.24	3.64	0.37
P_2O_5	-	1.48	0.98	0.02	0.08	< 0.05
SO_3	2.00	0.44	1.37	53.07	7.10	0.15
LoI	0.50	3.12	7.11	4.09	5.64	1.03

EXPERIMENTAL METHOD

In this research the objective was to find out the best way to achieve good and consistent tests result for paving blocks made in the laboratory. A compression machine was used to fully compact the materials in single layer with 150 KN of load. A mould collar of 75 mm high was used to retain the material within the mould. Paving blocks made were190 x100 mm cross section and 80 mm thick. The compressive cubes made were 50 mm in size. Once cast the specimens were covered with a polythene sheet so that there would be no loss of water. On the next day all samples were de-moulded and then stored in curing chambers at a constant air temperature of 22±2 degrees C and 98% relative humidity until they were to be tested.

BS EN 1338: 2003 was used to determine the tensile splitting strength of the paving blocks and the tensile force was applied along the longest side of the specimen block. Prior to the test the block specimen was located in the split tensile steel frame, using wood pieces on the top and bottom of the specimen to provide packing. Contact was made between the platens of the loading machine and the top and bottom of the steel plates of the testing frame, before the load was slowly applied at a rate of 0.05 ± 0.01 MPa/s until the point of failure. At this point the test was brought to an end and the specimen divided into two halves by tensile force. A record was made of the failure load and the tensile splitting stress was calculated in MPa according to BS EN1338: 2003. The standard requires a minimum tensile strength of

3.6 MPa for paving blocks in order to be acceptable by the industry. The compressive strength of the specimens was determined using a compression testing machine with a maximum capacity load of 2000KN, according to BS EN 12390-3:2009 standard. For the cubes, the compression load was applied to the face with a nominal area of 50x50mm cubes. Blocks and cubes were tested after 14 and 28 days.

Four groups of binary and ternary mixtures were designed with five to seven different proportions as shown in figures 1 to 4. The water content for all groups of mixes was constant at 15 per cent by weight of total materials used.

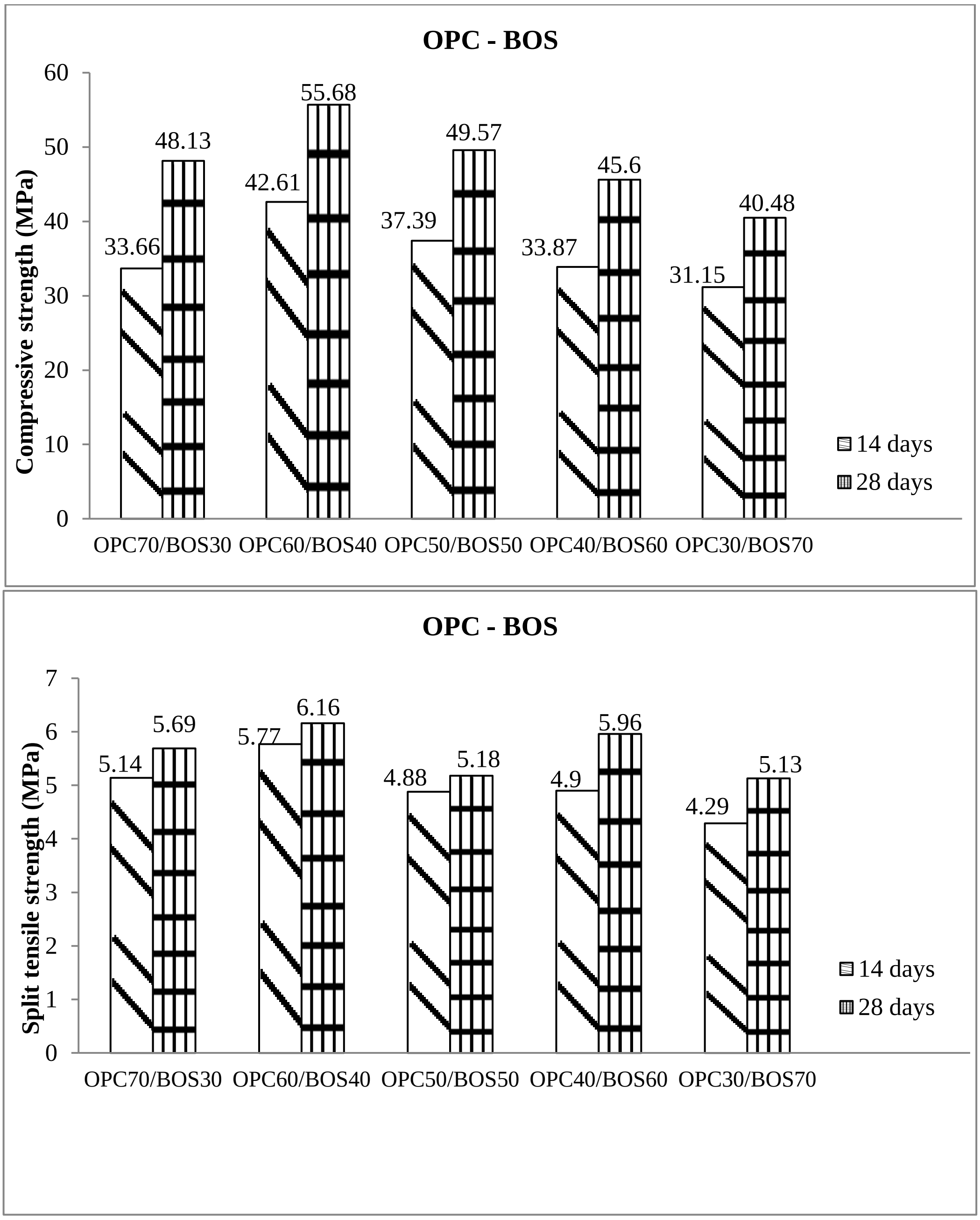

Figure 1. Compressive strength of 50x50mm cubes and tensile strength of blocks at 14 and 28 days.

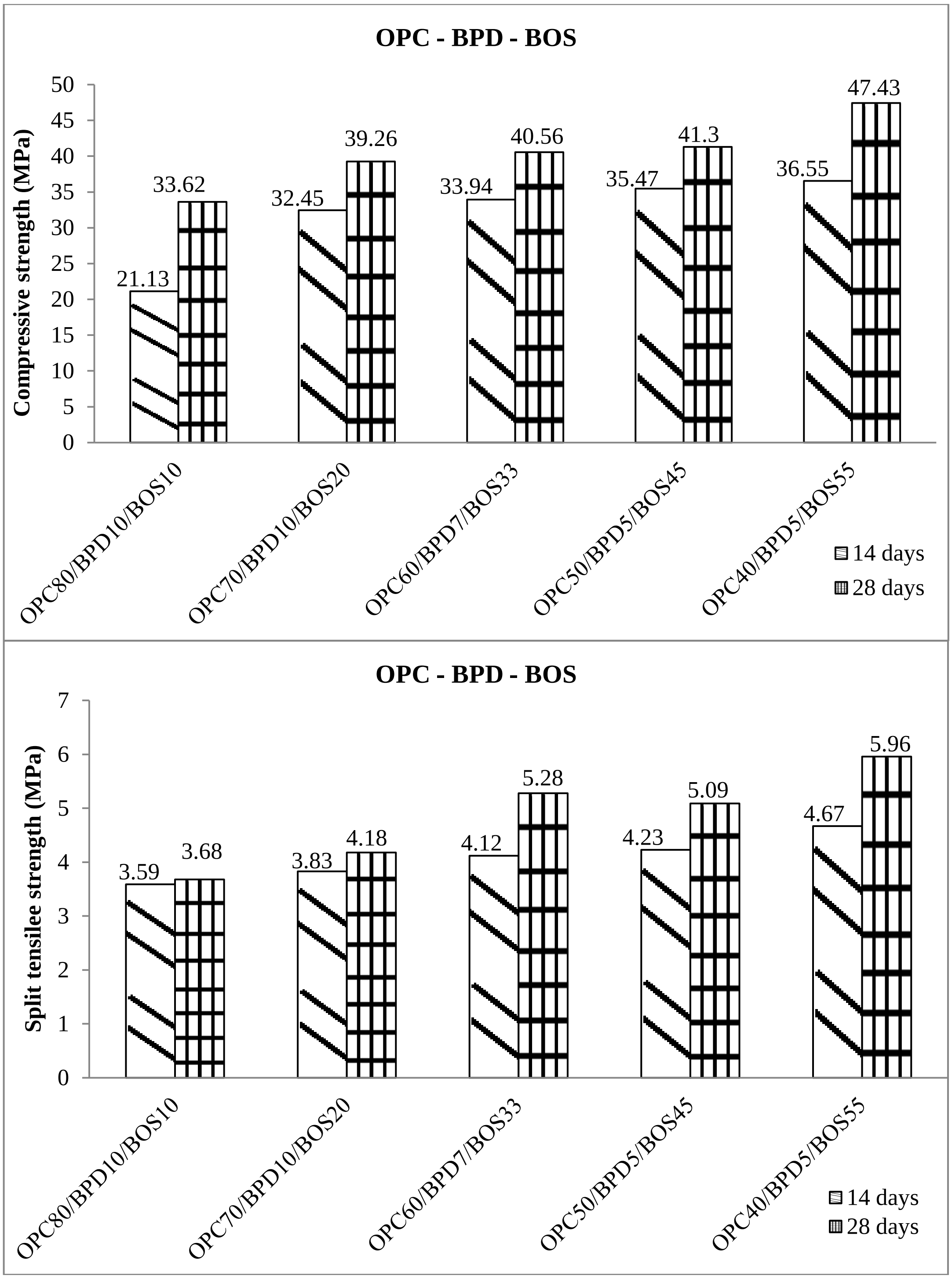

Figure 2. Compressive strength of 50x50mm cubes and tensile strength of blocks at 14 and 28 days.

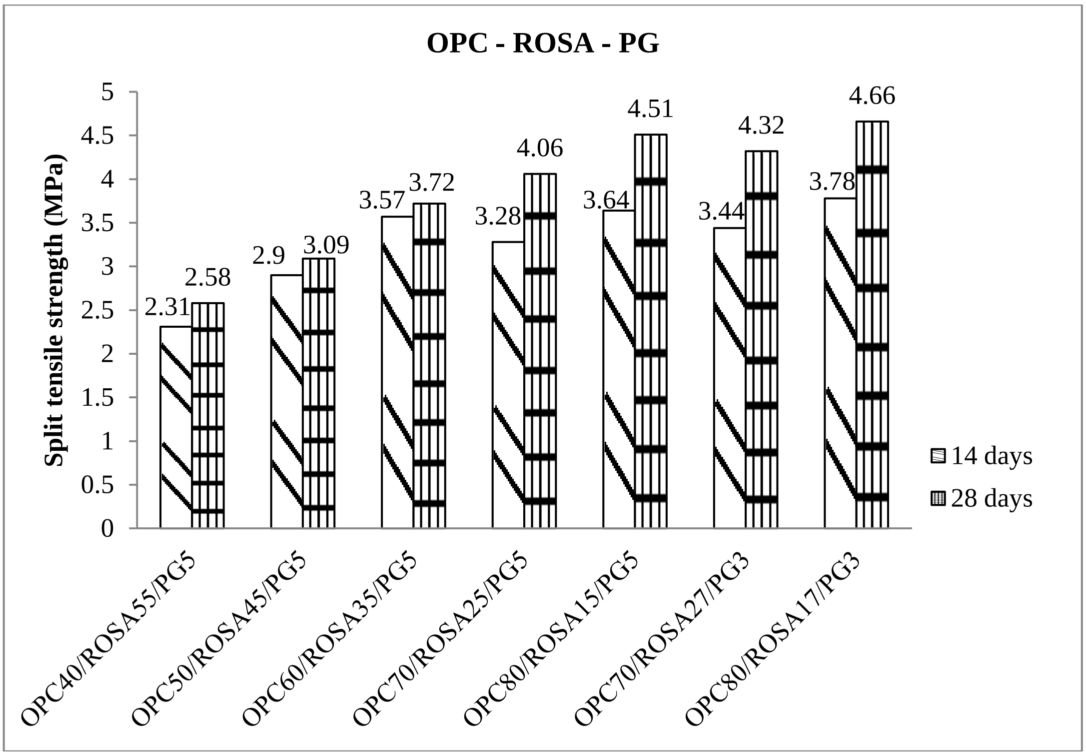

Figure 3. Tensile strength of blocks at 14 and 28 days.

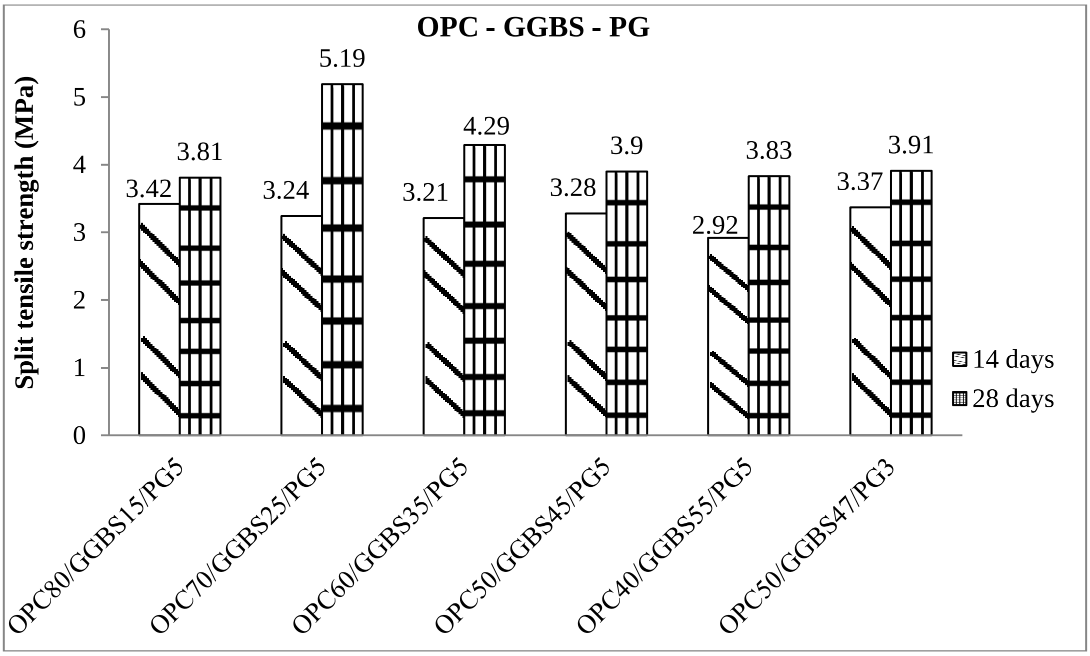

Figure 4. Tensile strength of blocks at 14 and 28 days.

RESULTS AND DISCUSSION

The results of tensile and compressive strength for all mixtures are shown in figures 1 to 4. The results of binary BOS and OPC (Fig 1) show that 40% BOS and 60% OPC produces the highest strength. Furthermore, by adding BPD, as source of more alkali and silicates, in the mixture for the ternary mix of OPC/BPD/BOS (Fig 2), the replacement level of cement is increased by up to 60 percent. The actual optimization result for this group is depicted in figure 5. The optimum range of BOS for the ternary mix of OPC/BPD/BOS is about 32 to 45 percent. In general, BOS typically hydrates after mixing with Portland cement or other alkali materials, such as; BPD which provides a source of alkalinity with which the slag reacts to form cement hydration products. The excessive amount of alkali in the system has a detrimental effect on the hydration of alkali activated slag causing low strength and a delay in setting. The precise causes for this behaviour have not yet been clarified. The formation of monosulphate due to instability of ettringite at high pH could be suggested to be the main reason.

The sulphate activation of waste run of station ash and GGBS by using plasterboard gypsum to produce a composite binder has been investigated in OPC/ROSA/PG and OPC/GGBS/PG groups. The groups will use sulphate activated mixes which depend on sulphate-slag reaction in order to set and gain strength. A maximum of 5 percent plasterboard gypsum waste was incorporated as a binder replacement to achieve the highest compressive strength. This was limited to 5 percent as literature confirms that increasing the PG content more than this will decrease the strength due to the gypsum reacting with cement hydration products; as this will cause expansion and reduce the strength of the binder mixes.

Figures 6 and 7 illustrate the results of optimization, the figures show that the optimum proportion of gypsum in ternary mixtures depends on the chemical properties of run of station ash and slag used. Using 5 percent plasterboard gypsum in combination with OPC/ROSA and OPC /GGBS to partially replace cement showed satisfactory results for use as paving blocks. This is because both groups satisfy the required minimum strength criteria, although in case of GGBS/PG after 28 days of age.

From figures 6 and 7 it is also observed that two sources of pozzolan in this investigation result in different ternary proportions corresponding to the highest compressive strength. In the study, the optimum range for ROSA in the ternary mix of OPC/ROSA/PG is between 20-45 percent and the optimum range for GGBS in the ternary mix of OPC/GGBS/PG is about 23-28 percent.

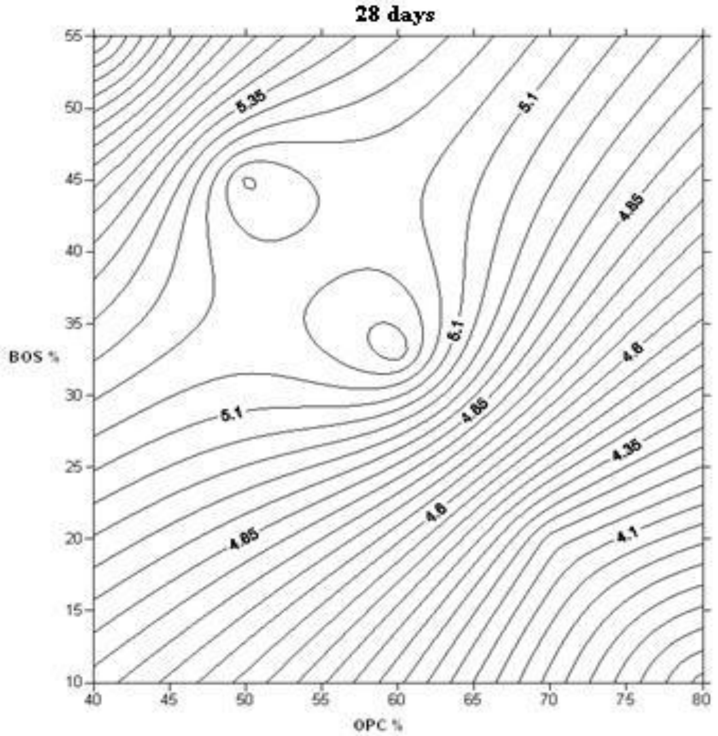

Figure 5. Splitting tensile strength (MPa) contour of the ternary OPC/BPD/BOS mix at 28 days.

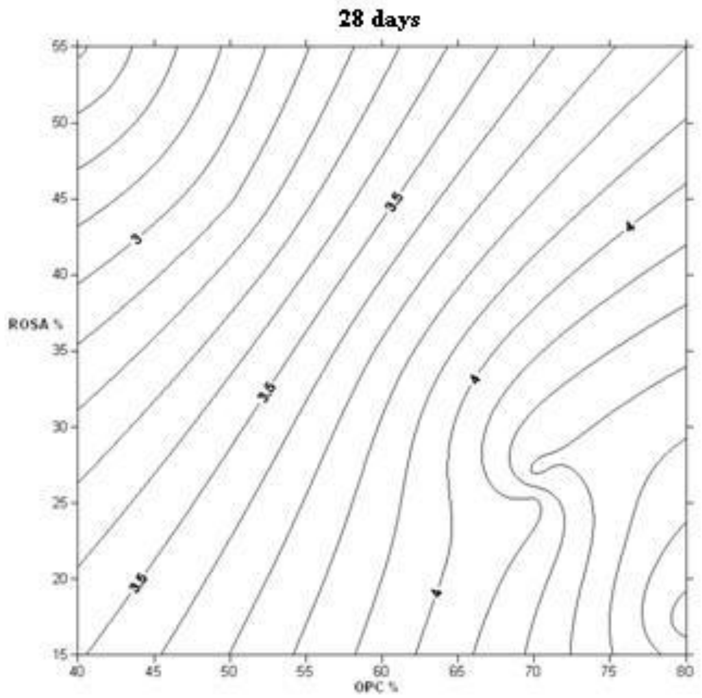

Figure 6. Splitting tensile strength (MPa) contour of the ternary OPC/ROSA/PG mix at 28 days.

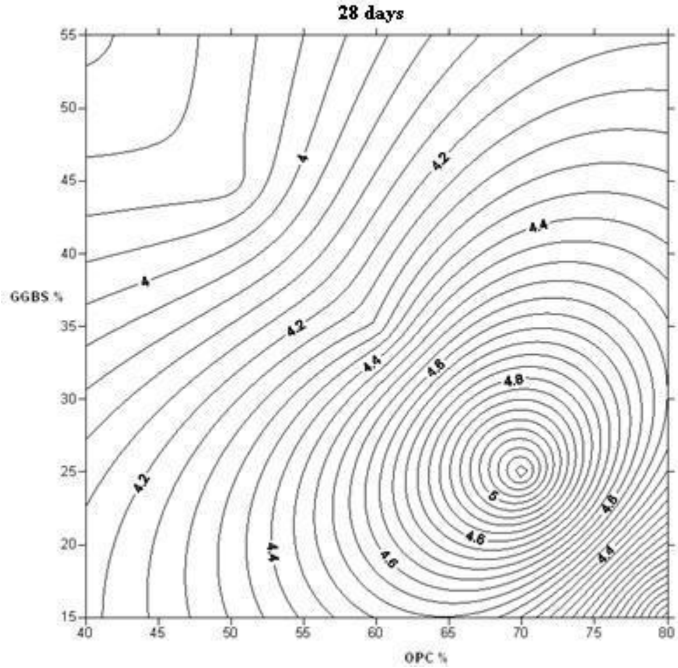

Figure 7. Splitting tensile strength (MPa) contour of the ternary OPC/GGBS/PG mix at 28 days.

The air dry densities of all the mixes are given in table 2. It can be seen that the densities for different groups change substantially due to the different specific gravities of the ingredients in each mix. The density ranges between about 1800 to 2400 kg/m^3 as expected.

Table 2. Density of blocks after 14 and 28 days for all mixes studied.

Mix code	**Density (Kg/m^3)**		**Mix code**	**Density (Kg/m^3)**	
	14 days	**28 days**		**14 days**	**28 days**
OPC70/BOS30	2295	2322	OPC60/ROSA35/PG5	1824	1839
OPC60/BOS40	2349	2338	OPC70/ROSA25/PG5	1872	1928
OPC50/BOS50	2381	2387	OPC80/ROSA15/PG5	1947	1975
OPC40/BOS60	2355	2370	OPC70/ROSA27/PG3	1953	1957
OPC30/BOS70	2374	2393	OPC80/ROSA17/PG3	1938	1958
OPC80/BPD10/BOS10	2187	2197	OPC80/GGBS15/PG5	2024	2077
OPC70/BPD10/BOS20	2250	2263	OPC70/GGBS25/PG5	1994	2003
OPC60/BPD7/BOS33	2234	2296	OPC60/GGBS35/PG5	1956	1977
OPC50/BPD5/BOS45	2281	2327	OPC50/GGBS45/PG5	1917	1948
OPC40/BPD5/BOS55	2336	2366	OPC40/GGBS55/PG5	1908	1943
OPC40/ROSA55/PG5	1715	1724	OPC50/GGBS47/PG3	2042	2052
OPC50/ROSA45/PG5	1774	1794			

CONCLUSION

The following conclusions can be drawn from this study:

1) It is possible to use waste minerals to achieve the minimum required tensile strength of 3.6 MPa for paving blocks in accordance to the British Standard BS BN1338: 2003.
2) Results show that ROSA up to 35%, BOS up to 70%, BPD up to 10%, GGBS up to 35% and PG up to 5% by weight can replace the Portland cement without negative impacts on their desirable properties in accordance to the BS EN 1338: 2003.
3) Up to 70 percent replacement of Portland cement can be achieved in binders and this can lead to reduced cement contents for production of paving blocks in accordance to the BS EN 1338: 2003.

REFERENCES

Bertolini, L., Carsana, M., Cassago, D., Curzio, A.Q. and Collepardi, M. (2004). “MSWI ashes as mineral additions in concrete”, Cement and Concrete Research, 34(10), pp.1899-1906.

BS EN 197-1. (2011). "Cement. Composition, specifications and conformity criteria for common cements", British Standard Institute, London.

BS EN 1338: (2003). "Concrete paving blocks requirements and test methods ", British Standard Institute, London.

BS EN 12390-3: (2009). " Testing hardened concrete. Compressive strength of test specimens", British Standard Institute, London.

BS 6699 (1992). "Specification for ground granulated blast furnace slag for use with Portland cement", British Standard Institute, London.

Ganjian, E. and Sadeghi-Pouya, H. (2009). "Investigation on the use of industrial and construction-demolition wastes as cement replacement in concrete paving blocks". Con Mat 09 - ‘4th International Conference on Construction Materials: Performance, Innovations and Structural Implications’, S 6-2-3, Nagoya, Japan: 295-300

Ghataora G., Rischard, J. and James, J. (2004) "Summary Project Report on The Utilization of Recycled Aggregates Generated from Highway arising and Steel Slag fines". Birmingham: University of Birmingham.

Mehta, P.K. (2001) “Reducing the environmental impact of concrete”, Concrete International, 23(10), pp.61-66.

Mehta, P.K.(2002). “Greening of concrete industry for sustainable development”, Concrete International, 24(7), pp. 23-27.

Menéndez, G., Bonavetti V. and Irassar E. (2002). "Strength development of ternary blended cement with limestone filler and blast-furnace slag". International Journal of Cement Composites and Lightweight Concrete.

Olivier, J., Janssens-Maenhout, G. and Peters, J. (2012). "Trends in global CO2 emissions". PBL Netherlands Environmental Assessment Agency.

Turanli, L. Uzal, B. and Bektas F. (2004). "Effect of material characteristics on the properties of blended cements containing high volumes of natural pozzolans. Cement and Concrete Research, 34, 2277-2282.