REALIZAREA UNUI BETON CU PREȚ REDUS, PENTRU PAVAJE RUTIERE
DEVELOPMENT OF LOW-COST CONCRETE FOR ROAD PAVEMENTS

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The use of concrete road pavements in Greece is very limited while there are many benefits from their use, especially in road parts of high inclination and heavy track circulation. The development of low-cost concrete, tailor-made for pavements will contribute to this alternative road construction. The design and properties of this type of concrete, which could be applied by using conventional equipment, are presented in this paper. The technical characteristics of the concrete which includes local fly ash as hydraulic binder and steel slag as aggregate are well described, including long-term performance observation.

În Grecia, utilizarea betonului pentru pavaje rutiere este foarte limitată, deşi ea prezintă numeroase beneficii, în special pentru zonele cu înclinații mari şi trafic greu. Realizarea unor betoane cu cost redus, destinate pentru pavaje, va contribui la o alternativă în construcția de drumuri. În această lucrare se prezintă proiectarea şi proprietățile acestui tip de beton, care ar putea fi realizat prin utilizarea echipamentului convențional. Sunt, de asemenea, prezentate, caracteristicile tehnice, incluzând observații ale performanțelor pe termen lung, pentru betonul care include ca liant, cenuşa zburătoare şi ca agregat, zgura de oțelărie.

Keywords: *durability, mechanical properties, special concretes*

1.Introduction

The use of concrete pavements in Greece is limited. Apart from airport pavements and industrial floors, concrete pavements are used occasionally in cases such as the construction of high inclination roads, industrial access roads and toll gate areas. A parameter that influences the decision process in favor of asphalt pavements is the higher initial cost of concrete pavements including the cost of concrete and the need for special equipment for its placement and joint construction. Concrete pavements can be unreinforced (jointed plain concrete pavements), lightly reinforced (jointed reinforced concrete pavement) or heavily reinforced (continuously reinforced concrete pavement). The amount of reinforcement in concrete pavement construction may also increase its cost significantly [1].

In cases of heavy traffic concrete pavements maintain adequate skid resistance for longer, perform better under unexpected high loading and, generally, show less deterioration [2]. Also, concrete pavements seem to be particularly appropriate in hot climates or situations where very low subgrade strengths occur [3]. In such cases, the use of concrete pavements increases durability and reduces maintenance costs over their life-cycle, compared to bituminous pavements [2, 4]. In this direction, the introduction of low-cost alternatives would make the use of concrete pavements more favorable, even when the life-cycle cost is not taken into account for deciding the type of pavement to be used. It is very important, of course, to provide low-cost alternatives without compromising the ultimate performance of the pavement.

Since cement is the most cost-driving material in concrete [5], lowering its cost would involve either using less cement in the overall mixture or its substitution with alternative binders. Some industrial by-products such as blastfurnace slag, fly ash and silica fume are very well-known alternative binders that can replace cement without reducing strength or durability [6 - 8]. Generally, the use of slag and fly ash in highway construction is of great interest since it is considered economically viable and beneficial [9]. The cost reduction achieved depends on local availability and market value of these materials. In Greece, fly ash is the most abundant industrial by-product, produced at rates of 10 million tons per year, and is already being used for blended cement manufacturing [10]. Since the market value of fly ash is significantly lower than that of cement, economy could be achieved either by using blended cement with increased fly ash content or by directly substituting large volumes of cement (up to 60%) in the mixture with fly ash [11].

Another way of reducing the initial cost of concrete for pavements would be by improving the quality and reducing the overall required volume of concrete. Since concrete layer thickness calculation is based on the properties of concrete, a mixture with increased mechanical properties (compressive and flexural strength, elastic modulus and abrasion resistance) would require less concrete volume and would prolong its service life [12]. One way to increase strength is to increase the cement content which, however, would also increase sharply the cost of the produced concrete. If, however, the concrete mixture was optimized by

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using lower water to binder ratio, suitable amount of superplasticizers to achieve the required workability, and aggregates of higher resistance to abrasion, then higher performance concrete could be achieved without increasing cost [5]. One alternative higher strength aggregate available is steel slag, a by-product of the steel industry. Steel slag aggregates show increased density, hardness and resistance to wear compared to limestone aggregates [13] and when used as coarse aggregates in concrete mixtures, the produced strength shows increased strength and abrasion resistance [14].

Considering all the above and following extensive experimental work, the present study aims at proposing alternative low-cost, high performance concrete mixtures that could be used for the construction of concrete pavements with conventional road construction equipment.

2. Concrete mixture design

A series of concrete mixtures was produced in the laboratory, in order to determine the optimal concrete mixtures, suitable for the required pavement applications.

Some parameters were kept constant for all of the test mixtures: all the mixtures tested had low binder content (270-300 kg/m^3) with Portland cement content as low as possible or with blended cement of low clinker content; the water to binder ratio was kept constant at 0.50; and the mixtures had low but adequate workability (fresh concrete slump > 10 mm or 3-8 s Vebe time), in order to be sufficiently compacted.

After testing different laboratory mixtures it was decided to propose three different concrete mixtures. The constituents of the three proposed mixtures are shown in Table 1.

Mixture A was prepared with limestone aggregates and blended cement type CEM IV 32.5 B (according to EN 197-1 [15]) as binder, with a 50% content in fly ash, which was a pilot production made by the cement industry; Mixture B was prepared with limestone aggregates and binder consisting of 40% Portland cement type CEM I 42.5 (according to EN 197-1) and 60% fly ash, while Mixture C had the same binders and binder ratio while steel slag was used as coarse aggregates.

The aggregate gradation of the three mixtures is shown in Figure 1.

Table 1

Proportions of the proposed mixtures/ *Compoziții ale mortarelor considerate*

Materials / *Materiale* (kg/m^3)	Mixture A *Amestec A*	Mixture B *Amestec B*	Mixture C *Amestec C*
Portland cement / *Ciment portland* CEM I 42.5	-	108	108
CEM IV 32.5-B	300	-	-
Fly ash / *Cenuşă de termocentrală*	-	162	162
Water / *Apă*	150	139	139
Natural fine aggregate / *Agregat fin, natural* (0-4 mm)	603	656	400
Slag fine aggregate / *Agregat fin de zgură* (0-4 mm)	-	-	400
Coarse limestone aggregate / *Agregat grosier din calcar* (4-31.5 mm)	1344	1273	-
Coarse slag aggregate / *Agregat grosier din zgură* (4-31.5 mm)	-	-	1628
Superplasticizer / *Superplastifiant* (~1% wt. of the total binder / *gravimetric, raportat la total liant)*	1.8	3	3

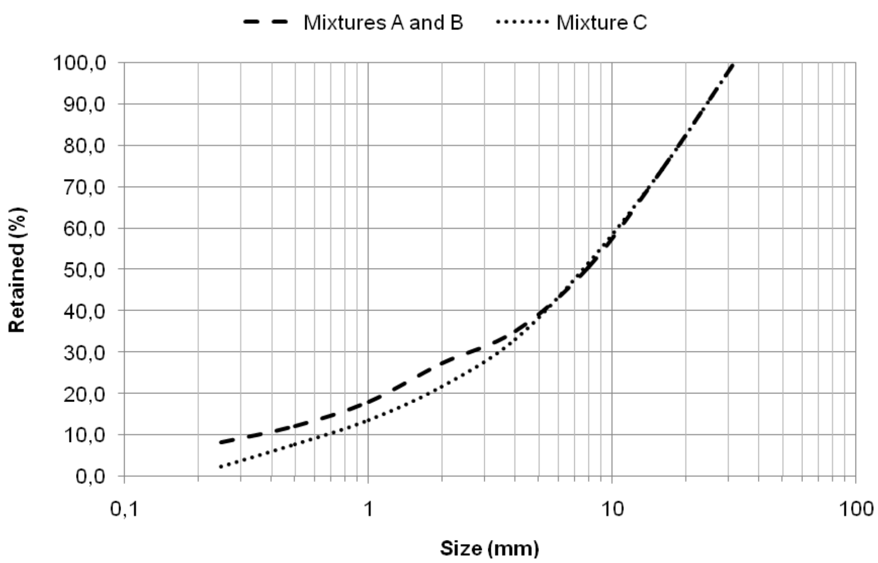

Fig. 1 - Aggregate gradation curves of the proposed mixtures / *Curbe granulometrice ale agregatelor pentru amestecurile de beton considerate.*

The consistency of the mixtures was measured with the Abrams cone and the Vebe apparatus, showing 10 mm slump and a Vebe time of 8 s, respectively. The specimens cast from all of the mixtures were cured for 28 days at 20°C and 95% RH until testing.

3. Performance of the proposed concrete mixtures

The laboratory concrete mixtures were tested for compressive, split tensile and flexural strength, modulus of elasticity and abrasion resistance at 28 days. Abrasion resistance was measured according to ASTM C779-00, which measures the gauge depth caused from the abrasive action of metallic rollers on the concrete surface. From the results (Table 2) it seems that the proposed mixtures have adequate strength development (at least C16/20) and modulus of elasticity greater than 30 GPa.

The mixture with 60% fly ash replacement of Portland cement (Mixture B) seemed to develop higher strength levels compared to the mixture with blended cement (Mixture A). Fly ash, however, is a pozzolan and tends to develop strength at a slower rate compared to Portland cement, so the strength of all of the mixtures is expected to increase further [6].

Regarding the use of steel slag aggregates, Mixture C shows increased mechanical properties such as the 10% increase in compressive strength and modulus of elasticity, compared to Mixture B with limestone aggregates. Apparent specific density of slag aggregate mixtures is also increased by 18%, reaching 2782 kg/m^3. The greater influence of the use of steel slag aggregates, however, is the significant increase in abrasion resistance, from 2.7 and 2.3 mm for Mixtures A and B, respectively, to 1.1 mm for Mixture C.

Concrete mixtures B and C –slightly modified– were used in pilot projects for the construction of test concrete pavements in order to evaluate their long term performance. A 200 m pilot test road was constructed in the area of Grevena, Greece, with concrete Mixture B (Figure 2), and a 240 m pilot test road was constructed with concrete Mixture C (Figure 3).

Both roads were constructed in rural areas, in order to serve heavy truck traffic loads by local asphalt and ready-mix concrete plants. The concretes used were mixed and placed with ordinary ready-mix concrete equipment and had adequate workability in order to be compacted with internal vibration. The subgrade construction, the concrete layer depth and joint construction was

Table 2

Some mechanical properties of the proposed mixtures measured at 28 days
Unele proprietăți mecanice ale mortarelor considerate, la 28 zile

Property / *Proprietatea*	Mixture A *Amestec A*	Mixture B *Amestec B*	Mixture C *Amestec C*
Apparent specific density */ Densitatea aparentă (kg/m^3)*	2346	2358	2782
Cylindrical compressive strength / *Rezistența la compresiune, pe cilindrii (MPa)*	23.9	30.7	33.7
Split tensile strength / *Rezistența la întindere prin despicare (MPa)*	3.21	3.47	3.68
Flexural strength / *Rezistența la încovoiere (MPa)*	5.88	6.62	6.69
Modulus of elasticity / *Modulul de elasticitate (GPa)*	30.6	35.7	39.3
Abrasion resistance – gauge depth / *Rezistența la abraziune – măsurată prin grosimea stratului erodat (mm)*	2.7	2.3	1.1

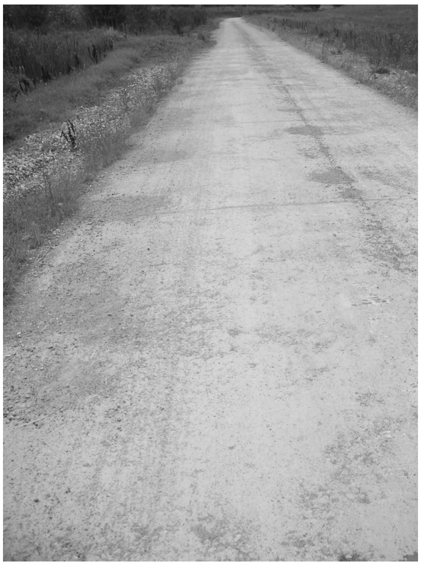

Fig. 2 - Pilot road constructed with high volume of fly ash and limestone aggregates / *Construcție pilot a drumului, cu beton cu volum mare de cenuşă şi agregat calcaros.*

Fig. 3 - Pilot road constructed with high volume of fly ash and steel slag aggregates / *Construcție pilot a drumului, cu beton cu volum mare de cenuşă şi agregat constând din zgură de oțelărie.*

similar to that used in ordinary concrete pavements.

After more than 7 years of use, both pilot roads were inspected visually and seemed to perform satisfactorily, despite heavy load traffic and wetting-drying cycles induced by local and environmental conditions. Only minor cracking at the edges was observed –caused primarily by the lack of shoulder support– and the surface showed little wear from abrasion. Drilled core specimens were taken to the laboratory and were tested in compression. The results were compared to the initial strength of the concrete showing adequate strength levels (Table 3).

Since compressive strength is related to the other mechanical properties of concrete (modulus of rupture, modulus of elasticity) the results show that the concretes tested maintain their strength levels and, hence, their serviceability. Also, the visual inspection showed good surface condition and minimal wear from abrasion.

initial cost of concrete with the use of high volumes of alternative materials is very possible if concrete mixtures are designed probably.

The by-products used in the proposed mixtures, as stated earlier, show some desirable characteristics as construction materials. The use of fly ash as a binder and steel slag as aggregate in concrete have been thoroughly researched and seem to be beneficial for the final product. Long-term tests of pilot concrete pavements were very positive, showing good durability of these concretes in practice without any maintenance, which implies that the cost of maintenance may be significantly reduced. High volumes of alternative materials can be used in concrete production, but mix proportioning needs also to be adjusted. The use of Greek fly ash requires workability adjustment with the use of a suitable superplasticizer, while the incorporation of steel slag as aggregates requires the combined aggregate gradation mix and the increased specific density of the concrete to be taken into account.

Table 3

Compressive strength of concretes used in pilot pavements construction
Rezistența la compresiune a betoanelor utilizate în experimentările pilot - pavaje

Property / *Proprietatea*	Concrete with high volume of fly ash and limestone aggregates / *Beton cu volum mare de cenuşă şi calcar, ca agregate*	Concrete with high volume of fly ash and steel slag aggregates / *Beton cu volum mare de cenuşă şi zgură de oțelărie, ca agregate*
28-day compressive strength / *Rezistența la compresiune la 28 zile (MPa)* (15 cm cubes / *cuburi de 15 cm*)	19.4	31.5
7 year compressive strength / *Rezistența la compresiune după 7 ani (MPa)* (calculated from drilled cores / *calculată pentru miezuri extrase din beton)*	23.9	34.4

4. Discussion and concluding remarks

The use of concrete with high volumes of industrial by-products seems a cost-effective way to produce rigid pavements. Provided that the same equipment for concrete pavement construction is used as in the case of bituminous asphalt roads, the total cost of a road construction project depends on the initial cost of construction and the cost of the required regular maintenance. The amount of cost reduction depends on the cement replaced by the usually cheaper alternative binders and calcareous fly ash can replace cement by more than 50% producing good quality concrete. It is worth mentioning that the current market price of fly ash is less than 40% than that of Portland cement, which allows for a market strategy on maximizing the use of calcareous fly ash in products for the road construction industry. Also, the use of steel slag aggregates can improve the mechanical properties of concrete and, thus, reduce the required volume, but cost reduction is limited and concerns areas at a short distance from slag-producing steel industries due to their high density and their subsequently increased transportation cost. Therefore, the reduction in the

The importance of keeping the water to binder ratio as low as possible and having adequate workability through the concrete mix design process is very important for the performance of the pavement. Furthermore, concrete pavement performance depends to a great extent on the construction practice followed. Sufficient subgrade strength specified concrete strength and layer size calculation, good concrete placement and compaction are all very important for the long-term performance of the pavement.

As it can be deducted from the test results, there is adequate strength development and durability of the produced concrete from the proposed mixtures. The data from the laboratory test concrete mixtures as well as from the pilot road construction show that the development of low-cost and good quality concrete mixtures for road pavements is feasible.

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