STUDIU PRIVIND APLICAREA MATERIALELOR PLASTICE TERMORIGIDE ÎN BETON

A STUDY ON APPLICATION OF RECYCLED THERMOSETTING PLASTIC IN CONCRETE

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Plastic waste management is one of the major environmental concerns in the world. Plastics can be separated into two types. The first type is thermoplastic, which can be melted for recycling in the plastic industry, such as polyethyleneterephthalate (PET). The second type is thermosetting plastic. This plastic cannot be melted by heating (such as melamine). At present, these plastic wastes are disposed by either burning or burying. Therefore, both the ways contributing to the environmental problems. This paper describes the use of thermosetting plastic waste as aggregate within lightweight concrete for building application and possibilities for re-use of thermosetting plastic waste in the concrete are described in detail.

Managementul deşeurilor din materiale plastice este o problemă majoră de mediu pe plan mondial. Materialele plastice pot fi clasificate în două categorii. În prima categorie se încadrează materialele termoplastice, care pot fi topite în vederea reciclării în industria materialelor plastice, cum ar fi PET. În prezent aceste deşeuri sunt eliminate prin ardere sau îngropare. Ambele solutii produc probleme de mediu. Aceasta lucrare prezintă utilizarea deşeurilor din materiale plastice termorigide ca agregate uşoare pentru aplicaţii în construcţii, posibilităţile de refolosire a acestor deşeuri fiind descrise în detaliu.

Keywords: *Recycled thermosetting plastic, composite, concrete*

1. Introduction

Plastic materials production has reached global maximum capacities leveling at 260 million tones in 2007, where in 1990 the global production capacity was estimated at an 80 million tones. It is estimated that production of plastics worldwide is growing at a rate of about 5% per year. Its low density, strength, user-friendly designs, fabrication capabilities, long life, light weight, and low cost are the factors behind such phenomenal growth. Plastics also contribute to our daily life functions in many aspects. With such large and varying applications, plastics contribute to an ever increasing Plastics can be separated into two types. The first type is thermoplastic, which can be melted for recycling in the plastic industry, such as polyethylene, polyamide and polyethylene-eterephthalate. The second type is thermosetting plastic. This plastic cannot be melted by heating because the molecular chains are bonded firmly with meshed crosslink [1-6].

The self weight of concrete elements is high and can represent a large proportion of the load on a structure. Therefore, using lightweight concrete with a lower density can result in significant benefits such as superior load-bearing capacity of elements, smaller cross-sections and reduced foundation sizes. A lightweight structure is also desirable in earthquake prone areas. It is convenient to classify the various types of lightweight concrete by their method of production [3-6]. These are:

a) By using porous lightweight aggregate of low apparent specific gravity, i.e. lower than 2.6, for example, pumice material. This type of concrete is known as lightweight aggregate concrete [7-9].

b) By introducing large voids within the concrete or mortar mass; these voids should be clearly distinguished from the extremely fine voids produced by air entrainment such as aluminum powder. This type of concrete is variously known as *aerated*, *cellular*, *foamed* or *gas* concrete [9-12].

c) By omitting the fine aggregate from the mix so that a large number of interstitial voids is present; normal weight coarse aggregate is generally used. This concrete is known as *no-fines* concrete.

In this research, the technology of aerated concrete to produce lightweight concrete has been employed. Since the specific gravity of thermosetting plastic is about one-half of the typical fine and coarse aggregates, therefore possibilities for application of thermosetting plastic waste in the concrete are investigated.

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2. Experimental

The materials used in present study are as follows:

Ordinary Portland Cement: Type I Portland cement conforming to ASTM C150-94.

Sand: Fine aggregate is taken from natural sand. Therefore, it was used after separating by sieve in accordance with the grading requirement for fine aggregate (ASTM C33-92). Table 1 presents the properties of the sand and its gradation is presented in Figure 1.

Thermosetting plastic: Melamine is a widely used type of thermosetting plastic. Therefore, in the present work has been selected for application in the mixed design of composite. The mechanical and physical properties of melamine are shown in Table 1. The melamine waste was ground with a grinding machine. The ground melamine waste was separated under sieve analysis. Scanning electron micrographs (SEM) of melamine aggregates is shown in Figure 2. Those have irregular shape and rough surface texture. The grain size distributions were then plotted as shown in Figure 1. It was observed that the gradation curve of the combination of sand and plastic aggregates after sieve number 16 meets most of the requirements of ASTM C33-92.

The melamine aggregates have been saturated surface dry. Therefore, melamine

Table 1

Properties of sand and melamine aggregates / *Proprietățile nisipului şi agregatelor din melamină*

Properties / *Proprietăți*	Sand / *Nisip*	Melamine
Density (g/cm^3) / *Densitate*	2.60	1.574
Bulk density / *Densitate in gramadă* (g/cm^3) (Melamine)	-	0.3-0.6
Water absorption / *Absorbția de apă* (%)	1.64	7.2
Max size / *Mărimea max.* (mm)	4.75	1.77
Min size /*Mărimea min.* (mm)	-	0.45
Sieve 200 / *Sita*, (%)	0.24	-
Flammability)/*Inflamabilitate* (Melamine)	non flammable *neinflamabil*	non flammable Decomposition
Decomposition/ *Descompunere* (Melamine)	-	at > 280 °C formation of NH_3 *formare de*

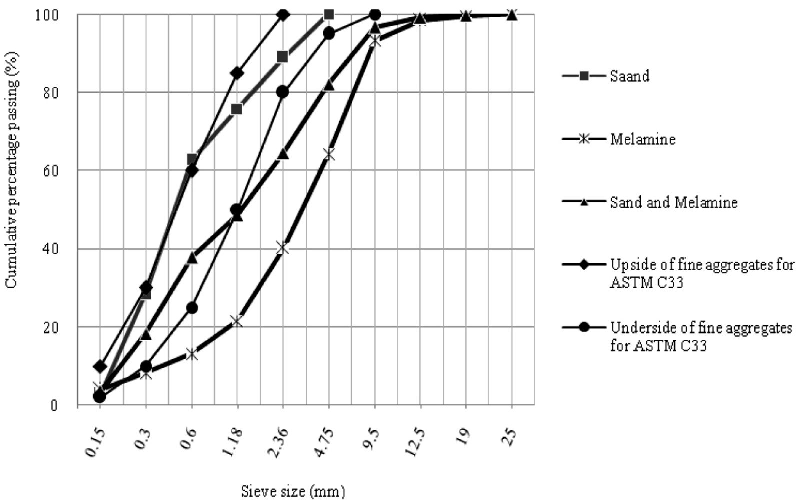
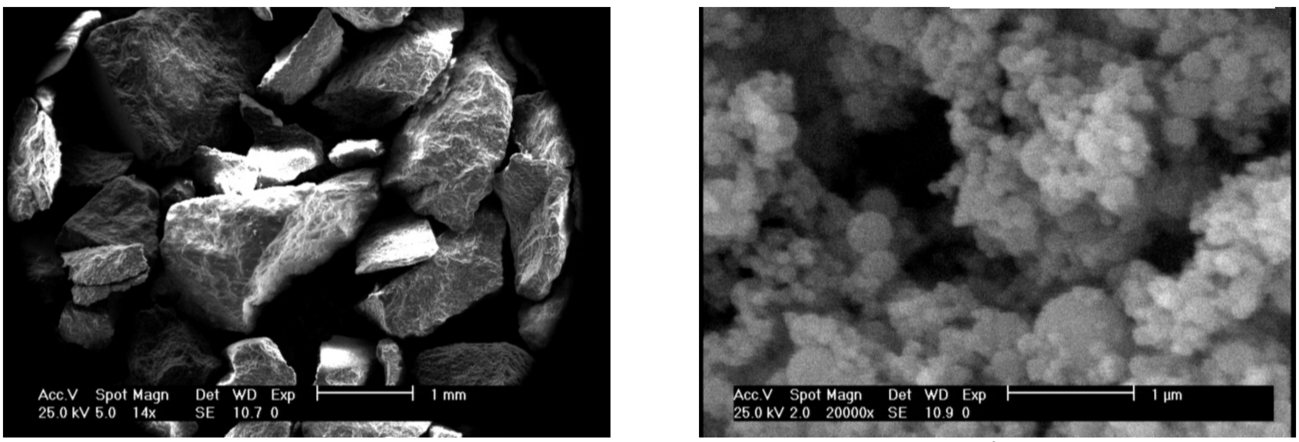


Fig. 1 - Gap-grading analysis of sand and melamine aggregates according to ASTM C33-92. *Analiza granulometrică a nisipului şi a agregatelor din melamină în conformitate cu ASTM C33-92.*



a b

Fig. 2 - SEM photographs of materials: (a) melamine aggregates and (b) silica fume / *Foto SEM ale materialelor: (a) agregate din melamină şi (b) praf de silice.*

aggregates immerse in water at approximately 21^oC for 24 h and removing surface moisture by warm air bopping.

Aluminum powder: In the present study, aluminum powder was selected as an agent to produce hydrogen gas (air entrainment) in the cement. This type of lightweight concrete is then called aerated concrete. The following are possible chemical reactions of aluminum with water:

$$2Al + 6H_2O \longrightarrow 2Al(OH)_3 + 3H_2 \quad (1)$$

$$2Al + 4H_2O \longrightarrow 2AlO(OH) + 3H_2 \quad (2)$$

$$2Al + 3H_2O \longrightarrow Al_2O_3 + 3H_2 \quad (3)$$

The first reaction forms the aluminum hydroxide bayerite ($Al(OH)_3$) and hydrogen, the second reaction forms the aluminum hydroxide boehmite ($AlO(OH)$) and hydrogen, and the third reaction forms aluminum oxide and hydrogen. All these reactions are thermodynamically favorable from room temperature past the melting point of aluminum (660^0C). All are also highly exothermic. From room temperature to 280^0C, $Al(OH)_3$ is the most stable product, while from $280\text{-}480^0C$, $AlO(OH)$ is most stable. Above 480^0C, Al_2O_3 is the most stable product. The following equation illustrates the combined effect of hydrolysis and hydration on tricalcium silicat.

$$3CaO.SiO_2 + \text{water} \longrightarrow xCaO.ySiO_2(aq.) + +Ca(OH)_2 \quad (4)$$

In considering the hydration of Portland cement it is demonstrate that the more basic calcium silicates are hydrolysed to less basic silicates with the formation of calcium hydroxide or 'slaked lime' as a by-product. It is this lime which reacts with the aluminium powder to form hydrogen in the making of aerated concrete from Portland cement:

$$2Al + 3Ca(OH)_2 + 6H_2O \longrightarrow 3CaO.Al_2O_3.6H_2O + 3H_2 \quad (5)$$

Hydrogen gas creates many small air (hydrogen gas) bubbles in the cement paste. The density of concrete becomes lower than the normal weight concrete due to this air entrainment.

Silica fume: In the present work, Silica fume has been used. Its chemical compositions and physical properties are being given in Table 2 and Table 3, respectively. Scanning electron micrographs (SEM) of silica fume is shown in Figures 2.

Superplasticizer: Premia 196 with a density of 1.055 ± 0.010 kg/m^3 was used. It was based on modified polycarboxylate.

Table 2

Chemical composition of Silica fume
Compozția chimică a prafului de silice

Chemical composition *Compoziția chimică*	Silica fume *Praf de silice*
SiO_2 (%)	86-94
Al_2O_3 (%)	0.2-2
Fe_2O_3 (%)	0.2-2.5
C (%)	0.4-1.3
Na_2O (%)	0.2-1.5
K_2O (%)	0.5-3
MgO (%)	0.3-3.5
S (%)	0.1-0.3
CaO (%)	0.1-0.7
Mn (%)	0.1-0.2
SiC (%)	0.1-0.8

Table 3

Physical properties of Silica fume
Proprietățile fizice ale prafului de silice

Items *Caracteristica*	Silica fume *Praf de silice*
Specific gravity *Greutatea specifică* (gr/cm^3)	2.2 – 2.3
Particle size (μm) *Mărimea particulelor*	<1
Specific surface area *Suprafa specific* (m^2/gr)	15 - 30
Melting point (^0C) *Temperatura de topire*	1230
Structure *Structura*	amorphous *amorfă*

2.1. Mix design

To determine the suitable composition of each material, the mixing proportions were tested in the laboratory, as shown in Table 4. In this study, the mix proportions were separated for five experimental sets. For each set, the cement and Aluminum powder contents was specified as a constant proportion. The proportion of each of the remaining materials, i.e. sand, water, silica fume, aluminum powder, and melamine, was varied for each mix design.

2.2. Experimental techniques

Mortar was mixed in a standard mixer and placed in the standard mold of 50 × 50 × 50 mm according to ASTM C109-02. In the pouring process of mortar, an expansion of volume due to the aluminum powder reaction had to be considered. The expanded portion of mortar was removed until finishing. The fresh mortar was tested for slump according to ASTM C143-03. The specimens were cured by wet curing at normal room temperature. The hardened mortar was tested for dry density, compressive strength, water absorption and voids for the curing age of 7 and 28 days. The test results for melamine, sand and water contents were reported for 7 days curing age for mix nos. 1–3, because these were very close to the results of 28 days. When silica fume was added in the latter mix nos. 4 and 5, the test

Table 4

Mix proportion of melamine lightweight composites (by weight) / *Compoziția compozitului uşor pe bază de melamină (raportat la greutate)*

Mix. No *Amestec numărul*	Cement *Ciment*	Aluminium powder *Praf de aluminiu*	Sand *Nisip*	Water *Apă*	Silica fume *Praf de silice*	Melamine *Melamină*	Superplasticizer *Superplastifiant*
1. Determination of melamine content (1st trial mix design) *Determinarea cantității de melamină (primul amestec)*	1.0	0.004	1.0	0.35	-	1.0	-
						1.5	
						2.0	
						2.5	
						3.0	
2. Determination of sand content *Determinarea cantității de nisip*	1.0	0.004	1.0	0.35	-	1.0	-
			1.2				
			1.4				
			1.6				
			1.8				
3. Determination of water content or water-cement ratio (w/c) Determinarea cantității de apă şi raportul A/C	1.0	0.004	1.4	0.30	-	1.0	
				0.35			
				0.40			
				0.45			
				0.50			
				0.55			
4. Determination of silica fume content *Determinarea cantității de praf de silice*	1.0	0.004	1.4	0.35	0.10	1.0	0.005
					0.15		0.007
					0.20		0.009
					0.25		0.012
					0.30		0.015
					0.35		0.020
5. Determination of melamine content (final mix design) *Determinarea cantității de melamină (ultimul amestec)*	1.0	0.004	1.4	0.35	0.25	1.0	0.012
						1.2	0.011
						1.4	0.010
						1.6	0.009
						1.8	0.008
						2.0	0.007
						2.2	0.006

Table 5

Specification of non-load-bearing lightweight concrete (ASTM C129) / *Caracteristici ale betonului uşor nestructural (ASTM C129)*

Type *Tip*	Compressive strength / *Rezistența la compresiune* (MPa)		Density (kg/m^3) *Densitate*
	Average of three unit *Rezultate medii pe trei probe*	Individual unit *Rezultate individuale*	
II	4.1	3.5	< 1680

results were presented for 28 days. This is because the presence of silica fume increases the duration for completion of the chemical reaction. The testing procedures of dry density, water absorption and voids were performed according to ASTM C642-97 and compressive strength was performed according to ASTM C109-02.

3. Results and discussion

3.1. Mix number 1 (determination of melamine content for the first trial mix design)

Figure 3 present the variations in the compressive strength and dry density for 7 days age of mortars as a function of the value of melamine substitutes used. It can initially be seen, to increased melamine, the compressive strength and dry density of composites decreased. The reduction in the compressive strength is due to the addition of melamine aggregates or could be due to either a poor bond between the cement paste and the melamine aggregates or to the low strength that is characteristic of plastic aggregates. The absorption is an indirect parameter to examine the inside porosity of mortar. The results showed that the absorption after immersion and voids of mortar increased as the melamine content increased (see Figs. 4 and 5). Therefore, to increased melamine plastic, the inside porosity of mortar increased. This might be other reason for the reduction in the compressive strength and density.

3.2. Mix number 2 (determination of sand content)

The results of compressive strength and dry density for 7 days age are shown in Figure 6. It can be seen that a reduction of sand leads to a reduction in the strength and dry density. The compressive strength and dry density for sand

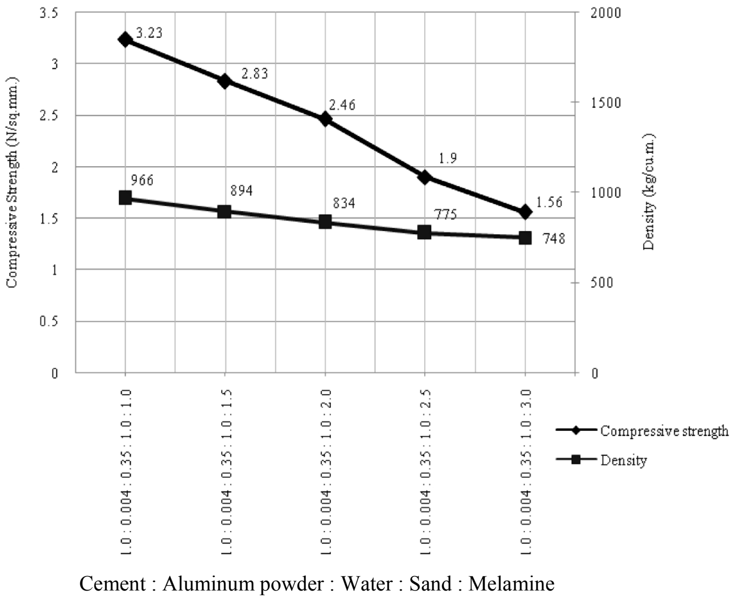


Fig. 3 - Compressive strength and density for varying melamine content (curing for 7 days) *Rezistența la compresiune şi densitatea pentru diferite cantități de melamină (tratare 7 zile).*

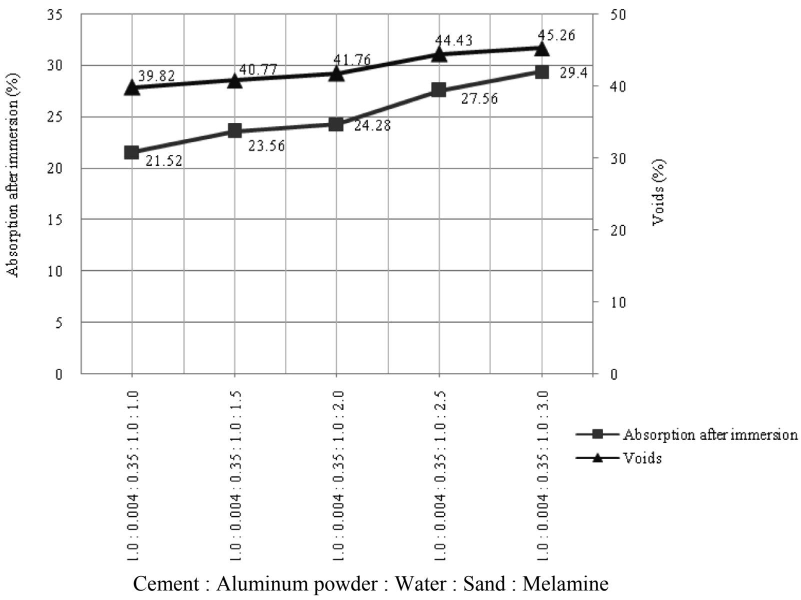


Fig. 4 - Absorption after immersion for varying melamine content (curing for 7 days) / *Absorbția după imersare pentru diferite cantități de melamină (tratare 7 zile).*

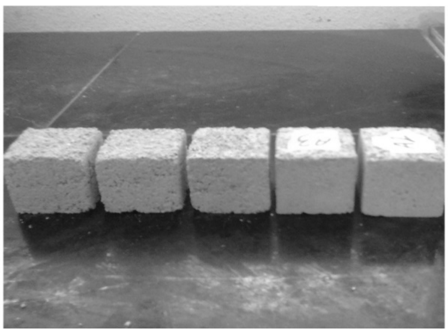


Fig.5 - Optical photographs of samples containing varying melamine, right to left containing 1.0, 1.5, 2.0, 2.5 and 3.0 the weight percentage of melamine / *Foto ale probelor conținând diferite cantități de melamină, de la stânga la dreapta conținând 1.0, 1.5, 2.0, 2.5 şi 3.0 procente de melamină raportate la greutate.*

content equal to or greater than 1.4 exactly satisfy the standard value.

Figs. 7 present the variations in the absorption after immersion and voids as a function of the value of sand substitutes used. The results showed that the absorption after immersion and voids of mortar decreased as the sand content increased.

3.3. Mix number 3 (determination of water content)

The results of compressive strength and dry density for 7 days age are shown in Figs. 8 and 9. The results showed that the compressive strength and dry density of mortar decreased as the water content increased.

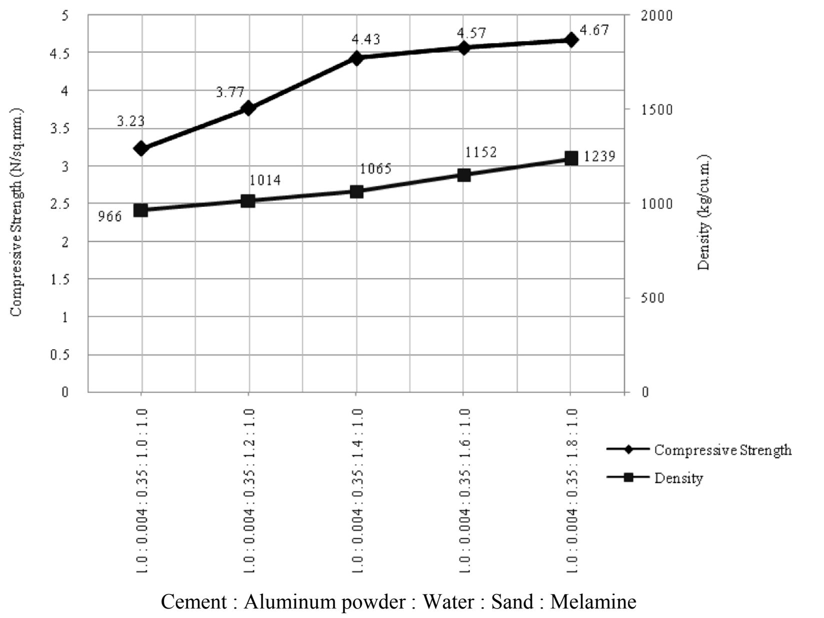


Fig. 6 - Compressive strength and density for the determination of the optimum sand content (curing for 7 days) / *Rezistența la compresiune şi densitatea pentru determinarea cantității optime de nisip (tratare 7 zile).*

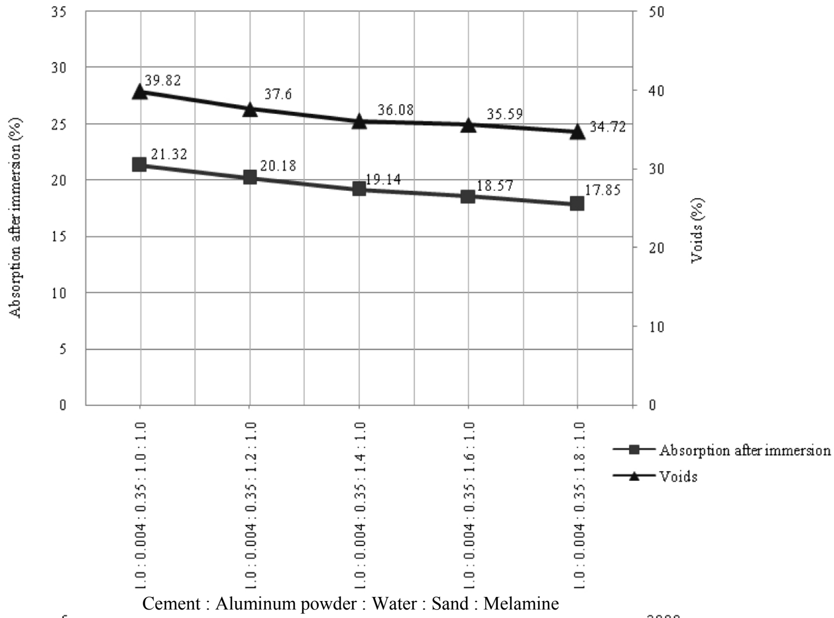


Fig. 7 - Absorption after immersion and voids for varying sand content (curing for 7 days) / *Absorbția după imersare şi procentul de goluri pentru diferite cantități de nisip (tratare 7 zile).*

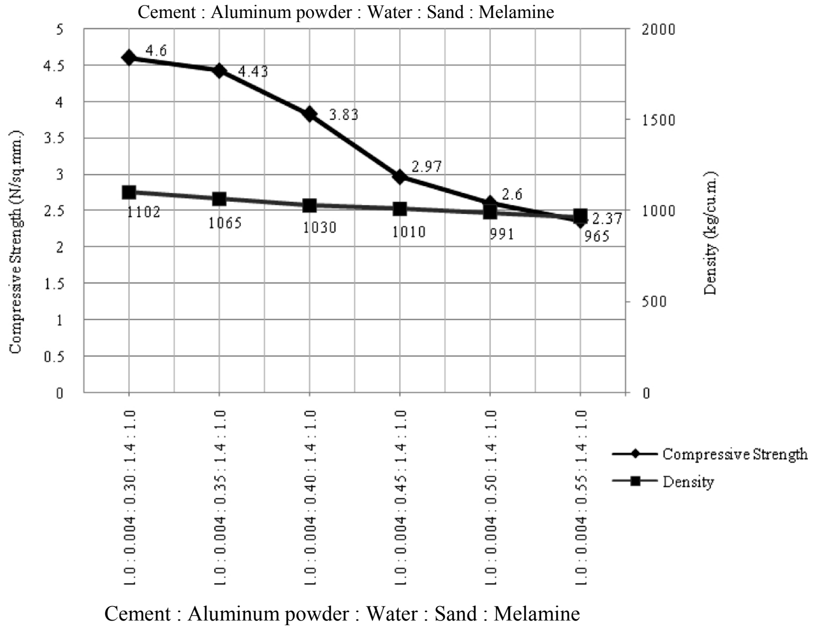


Fig. 8 - Compressive strength and density for the determination of the optimum water content (curing for 7 days) / *Rezistența la compresiune şi densitatea pentru determinarea cantității optime de apă (tratare 7 zile).*

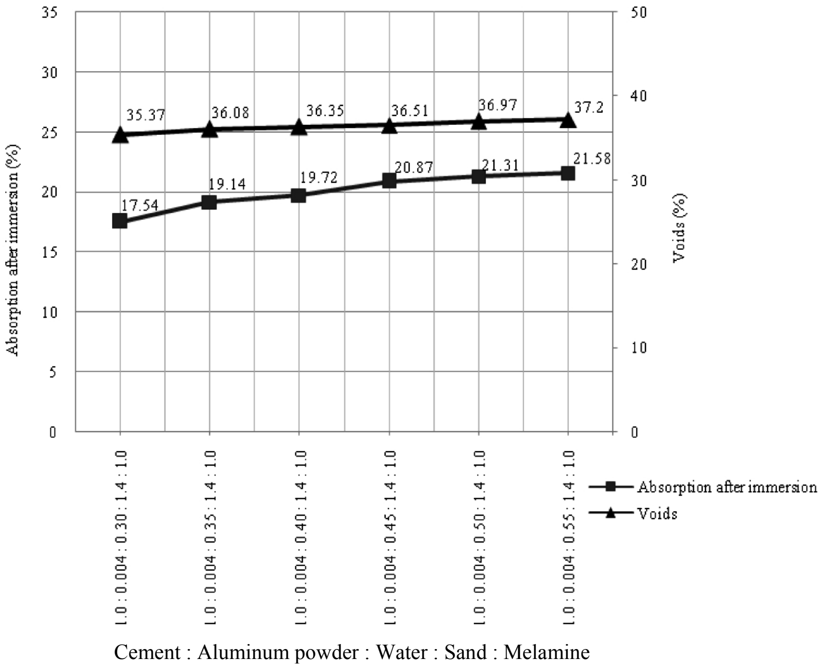


Fig. 9 - Absorption after immersion and voids for varying water content (curing for 7 days) / *Absorbția după imersare şi procentul de goluri pentru diferite cantități de apă (tratare 7 zile).*

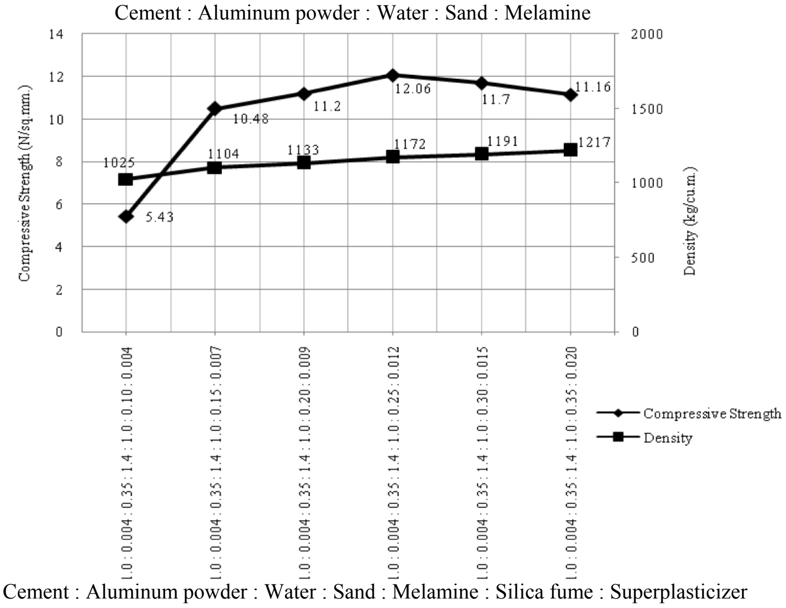


Fig. 10 - Compressive strength and density for the determination of the optimum silica fume content (curing for 28days) *Rezistența la compresiune şi densitatea pentru determinarea cantității optime de praf de silice (tratare 7 zile).*

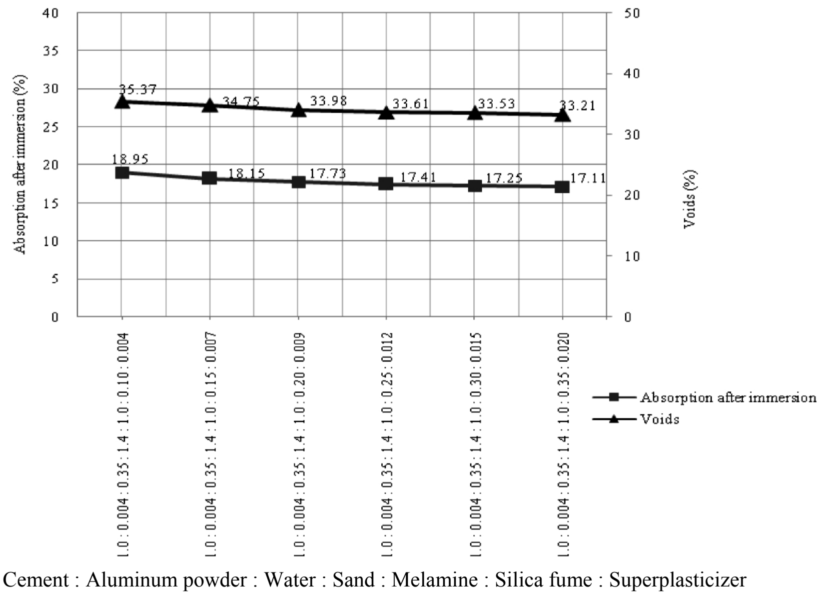


Fig. 11 - Absorption after immersion and voids for varying silica fume content (curing for 28days) / *Absorbția după imersare şi procentul de goluri pentru diferite cantități de praf de silice (tratare 7 zile).*

3.4. Mix number 4 (determination of silica fume content)

Figs. 10 and 11 present the variations in the compressive strength and dry density for 28 days age of mortars as a function of the value of silica fume substitutes used. It was found that the results of compressive strength for seven days age do not increase when compared with those without silica fume.

3.5. Mix number 5 (determination of the final melamine plastic content)

Figure 12 present the variations in the compressive strength and dry density for 28 days age of mortars as a function of the value of melamine substitutes used. It was found that the presence of melamine caused a reduction in the dry density and compressive strength of concretes as discussed previously.

Fig. 13 shows that the scanning electron microscopy analysis of composites reveals that cement paste-melamine aggregates adhesion is

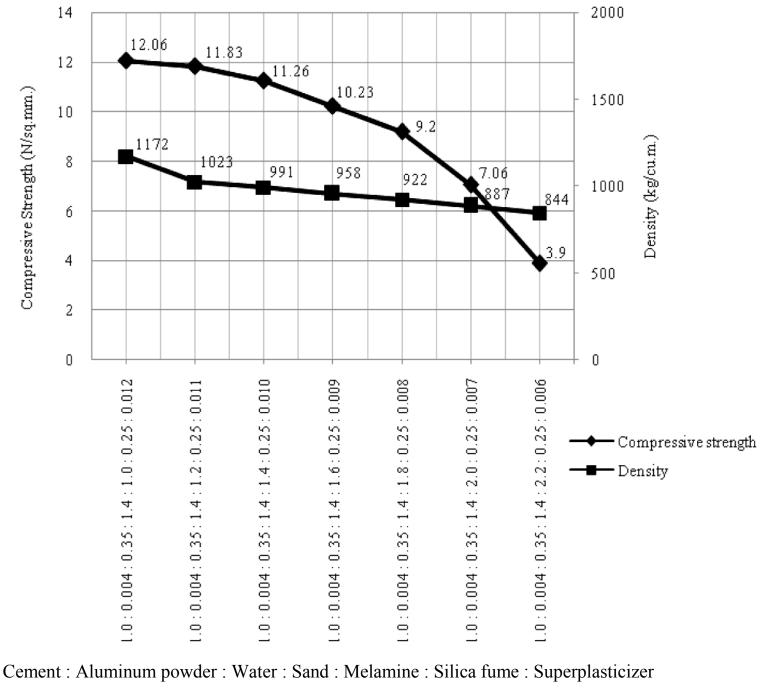


Fig. 12 - Compressive strength and density for the determination of the optimum melamine plastic content (curing for 28days)
Rezistența la compresiune şi densitatea pentru determinarea cantității optime de melamină (tratare 7 zile).

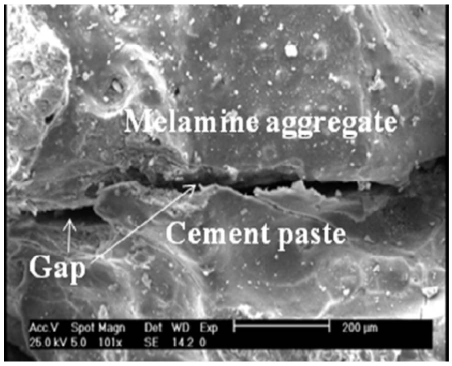


Fig. 13 - Microstructure of concrete containing 1.6 melamine by weight of cement, as obtained using SEM (enlargement: 101×) / *Microstructura betonului conținând 1.6 melamină raportată la greutatea cimentului obținută utilizând tehnica SEM (mărire: 101×)*

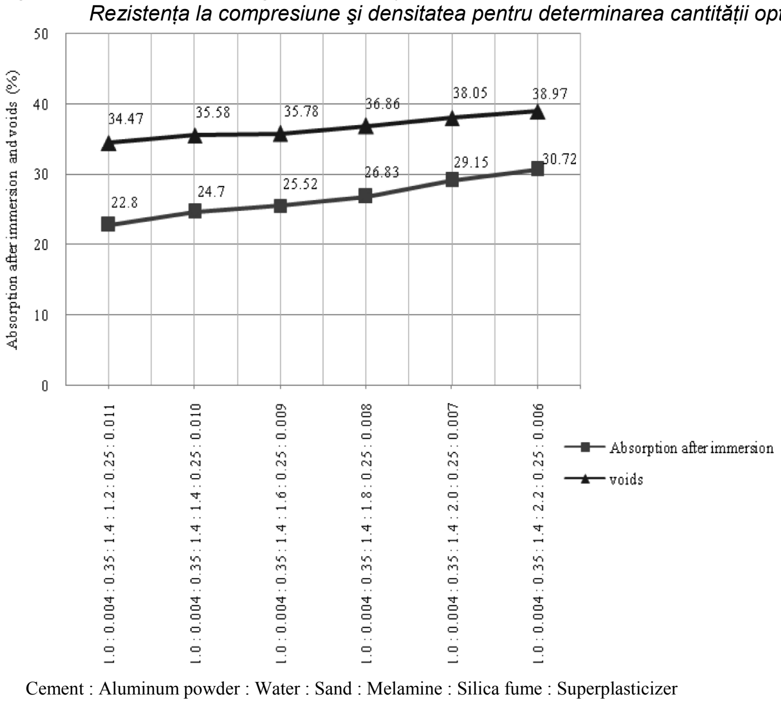


Fig. 14 - Absorption after immersion and voids for varying melamine plastic content (curing for 28days) / *Absorbția după imersare şi procentul de goluri pentru diferite cantități de melamină (tratare 7 zile).*

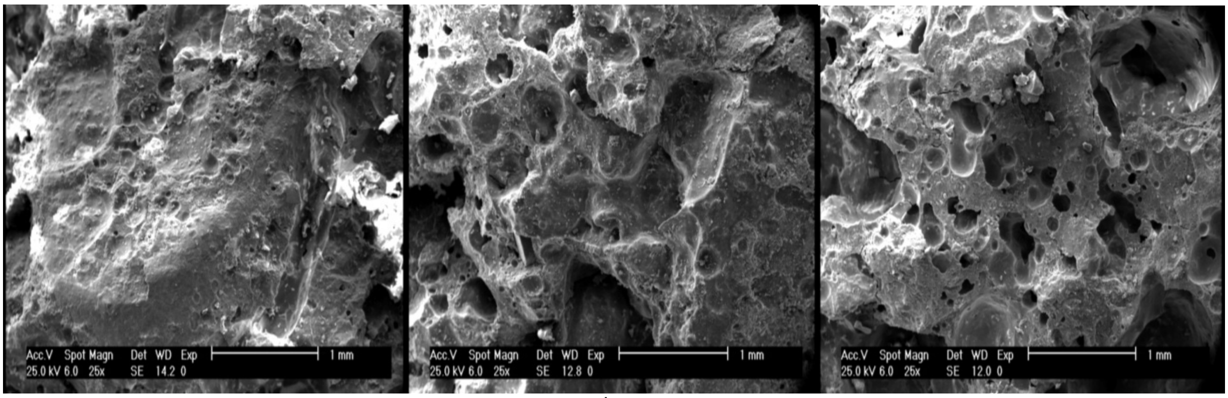


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Fig. 15- Scanning electron micrographs of various mortars containing melamine plastic aggregates. (a) 1.2 by weight of cement (enlargement: 25×). (b) 1.6 by weight of cement (enlargement: 25×).(c) 2.0 by weight of cement (enlargement: 25×) / *Foto SEM pentru mortare conținând diferite cantități de agregate din melamină. (a) 1.2 raportată la greutatea cimentului (mărire 25×) (a) 1.6 raportată la greutatea cimentului (mărire 25×) (a) 2.0 raportată la greutatea cimentului (mărire 25×).*

imperfect and weak. Therefore, the problem of bonding between plastic particles and cement paste is main reason to decrease of compressive strength. An optimum melamine content of 2.0 was selected. The results of compressive strength and dry density, which are 7.06 MPa and 887 kg /m3, are according to ASTM C129 Type II standard.

The results showed that the absorption after immersion and voids of mortar increased as the melamine content increased (see Fig. 14). Also, the structure analysis of mortars by scanning electron microscopy has revealed a low level of compactness in mortars when the value of melamine plastic increased (see Fig. 15). It was confirmed that to increased melamine plastic, the inside porosity of mortar increased.

4. Conclusions

Melamine plastic aggregates can be successfully and effectively utilized for nonload-bearing lightweight concrete according to ASTM C129 Type II standard. The following conclusions were drawn from the investigation:

1. With an increase of replacement ratio of materials of lightweight concrete by melamine plastic aggregates:
   a. the compressive strength and densities of the lightweight concrete were reduced;
   b. the absorption and volume of permeable voids of the lightweight concrete were increased.
2. The existed linear relationship between the compressive strength and density. Also, the existed inverse relationship between the compressive strength, density and absorption, volume of permeable voids.
3. Density and compressive strength of mortar decreased as the water content increased.
4. The compressive strength increase as the addition of SF increases.
5. Utilization of other plastics in the mix proportion for nonload- bearing lightweight concrete according to ASTM C129 Type II standard and other standards are suggested for further studies.

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