Composite Materials Based on Autoclaved Aerated Concrete Waste and Unsaturated Polyester Resin

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This paper presents an experimental study on the potential use of new type of composite as insulation material. The composite material (AACW-UPR) was synthesised through mixture between the Autoclaved Aerated Concrete Waste (AACW) as filler and Unsaturated Polyester Resin (UPR) as matrix. Several samples of the composite material with different UPR concentrations (50 and 70 vol.%) and different AACW particle size (0.2-1 mm, 1.5-2.5 mm, 3-6 mm) were prepared. The thermal behaviour and the water absorption capacity of the AACW-UPR composite materials were studied. Also, the influence of water absorption capacity on thermal resistance and thermal conductivity was studied. During the investigations we noticed the following: good chemical compatibility between the AACW particles and the UPR matrix; a decrease in thermal conductivity for samples with 50 vol.% UPR and inserted particles size between 3-6 mm and an increase in water absorption capacity with the increase in the filler content in the matrix. The increasing water absorption capacity determined a decrease in thermal resistance and a reduction of the composite features as insulating material.

Keywords: autoclaved aerated concrete, waste, unsaturated polyester resin, thermal conductivity, water absorption capacity

The worldwide increase in the amount of Autoclaved Aerated Concrete Waste (AACW) requires the identification of some ways for their recycling process. There are no good options proposed so far for recycling the AACW generated from construction and demolition. The impurities contained into the AACW could be a reason for reduced rate of its recycling.

The Directive 2008/98/EC on waste (Waste Framework Directive) includes two new recycling and recovery targets to be achieved by 2020: 50% preparing for re-use and recycling of certain waste materials from households and other origins, similar to households, and 70% preparing for re-use, recycling and other recovery of construction and demolition waste. EU target 2020: *minimum of 70%* C&D waste (by weight) must be prepared for re-using, recycling or backfilling [1].

The Autoclaved Aerated Concrete (AAC) is a lightweight microporous building material with a density of 400-800 kg/m^3 and thermal insulating capacity ranging 0.1-0.2 W/mK [2,3]. The AAC is one of the most commonly used lightweight construction material for contemporary buildings, especially due to its low density, good thermal and breathing properties and high fire resistance. However, this material has some disadvantages; for instance, its higher water absorption capacity makes it susceptible to deteriorations due to the water influence. The larger quantities of AAC used in constructions have resulted in the accumulation of huge amounts of waste. Although, the AACW is generated during the production process due to its non-compliance structural or shape.

Recycling such wastes as building materials appears to be a viable solution, not only to such pollution matters but also to the problem regarding economical design of buildings. However, the AACW recycling still remains a challenge.

A lot of studies focused on the use of the AACW have been performed. Thus, further research about the use of AACW as filtering or water purification materials were conducted. The fragmented AACW into grains with different sizes was used in various filtering media. As a conclusion from the performed studies the AACW particles must not contain impurities [4,5]. Usually, the AACW, generated from the demolition, contains a lot of impurities, so that its use constitutes an issue. Therefore, the studies were focused on the use of AACW as filler into materials for screeds. [6,7].

Some authors have investigated the use of AACW as lighting material in the structure of a green roof [8,9].

There is also a study that has evaluated the possibility to use the AACW as filler into composite materials with a matrix based on natural rubber [10].

A few scientists have studied the use of unsaturated polyester resin as matrix into composite materials. The mechanical and thermal behaviour of composite materials with UPR as matrix and different natural or synthetic fibres as filler was analysed [11,12].

The application of ash, obtained from fuel combustion reaction, as filler in concrete polymer was investigated [13].

The aim of this paper is to find out a possibility to recover the AACW and to use it as thermal insulation material. The thermal conductivity and water absorption capacity of the AACW-UPR composite materials with different UPR concentrations (50 and 70 vol.%) and different AACW particle size (0.2-1 mm, 1.5-2.5 mm, 3-6 mm) were studied.

Experimental part

Materials and methods

The technical characteristics of AAC bricks (produced by the Soceram) are given in table 1. The AAC particles were obtained through grinding the AAC bricks. Before grinding, the AAC bricks were stored into a room at the ambient temperature and humidity. The studied AAC bricks not contain impurities such as mortar, concrete or other

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Table 1
THE MAIN TECHNICAL CHARACTERISTICS OF AAC BRICK

Technical characteristics/ Caracteristici tehnice		Unit of measure/ Unitate de măsură		Values/Valori
Dimensions/ Dimensiuni	Length/Lungime	L	mm	650
	High/Înălțime	H		240
	Thickness/Grosime	T		150
Dry density/Densitate		ρ	kg/m3	500
Thermal conductivity/Conductivitate termică		λ	W/mK	0.13
Dimensional stability/Stabilitate dimensională			Mm/m	0.33
Water absorption/Absorbția de apă			%	47.6
The diffusion coefficient of water vapors/Coeficientul de difuzie al vaporilor de apă		μ		5/10
Compressive Strength/Rezistența la compresiune			N/mm2	3
Fire reaction/reactia la foc		Euroclass		A1

building materials. The ground material was sieved and obtained particles were divided into three classes of size, such as 0.2-1 mm (AAC_I), 1.5-2.5 mm (AAC_II), and 3-6 mm (AAC_III) (fig. 1). The grain size distribution of the AACW (AAC_I, AAC_II, and AAC_III) is presented in figure 2. The AAC particles were dried in an induced convection furnace at 50°C for 24 h.

The material used as matrix was based on commercially available unsaturated polyester, Polimal 109-32 PyK. The matrix was mixed using a curing catalyst like the methyl ethyl ketone peroxide (MEKP) at a concentration of 0.02 wt.%. The UPR physical parameters are presented in table 2.

There were prepared six samples with different particles size (0.2-1 mm, 1.5-2.5 mm, and 3-6 mm) representing 30%, respectively 50% from the volume fraction of the mixture (table 3). The sp1 sample does not contain AAC particles. In order to investigate the thermal conductivity, the hollow mould size must be 300 x 300 x 20 mm in accordance with the ISO 8301:1991 Standard (Thermal insulation - Determination of steady-state thermal resistance and related properties - Heat flow meter apparatus) [15]. The unsaturated polyester resin and methyl ethyl ketone peroxide (MEKP) catalyst were mixed and stirred for 3 to 5 minutes. In order to allow a proper dispersion of the AAC particles within the gel-like mixture, the AACW particles were gradually added and during the stirring. The mixture was poured into moulds which were previously smeared with anti-sticking agent. After the pouring process, the composite material was dried for 24 h at room temperature obtaining a completely hardened mixture. The visual aspect of the composite materials is shown in figure 3.

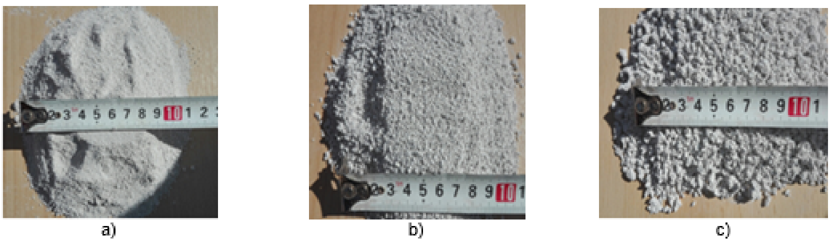

Fig.1. AAC waste with grain size: a) 0.2-1 mm (AAC_I), b) 1.5-2.5 mm (AAC_II) , c) 3-6 mm (AAC_III)

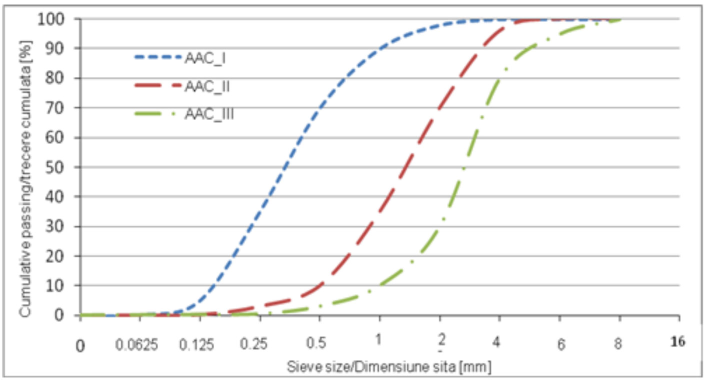

Fig.2. The grain size distribution of AACW

Table 2
THE MAIN TECHNICAL CHARACTERISTICS OF UPR

Density/ Densitatea [kg/m^3]	Viscosity/ Viscozitatea [mPa.s]	Flexural strength/ Rezistența la încovoiere [MPa]	Tensile modulus/ Modulul de tracțiune [MPa]	Tensile strength/ Tensiunea la rupere [MPa]	DHT/ Temperatura de deformare [^{0}C]
1150	230-290	100	3900	50	65

Table 3
SAMPLES COMPOSITION

Sample/ Cod proba	AAC/BCA [%]	UPR/Rășina poliesterică [%]	AAC grain size/Dimensiunea granulelor de BCA [mm]
sp1	-	100	-
sp2	50	50	0.2-1
sp3	30	70	0.2-1
sp4	50	50	1.5-2.5
sp5	30	70	1.5-2.5
sp6	50	50	3-6
sp7	30	70	3-6

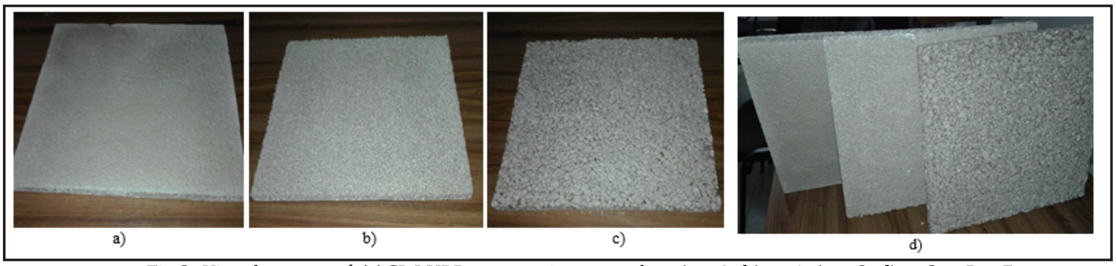

Fig.3. Visual aspect of AACW-UPR composites samples:a) sp2, b) sp4,c) sp6, d) sp3,sp5,sp7

The thermal conductivity was determined in accordance with EN 12667 Standard [13] by using a Hilton B480 thermal conductivity unit. The concept of a heat flowmeter is defined in the ISO 8301:1991 Standard [15]. The tested sample is placed between a hot plate and the heat flowmeter which is attached to a cold plate. The equipment is covered with an insulator. The Hilton B480 unit is based on the heat flowmeter method described. In order to measure the conductivity, the size of samples ranged in accordance with the ISO 8301:1991 Standard. The Hilton B480 unit is capable to sustain specimens of 300 x 300 mm, respectively 75 mm thickness. The grain size distribution of the AACW particles was determined according to the method presented in the EN 933-1 [16].

In order to study the behaviour of the AACW-UPR composite materials to water absorption, the experiments were carried out according to ASTM D570-98 [16]. Before the immersion, the samples were dried into a furnace at 50 ± 3 °C for 8 hand then cooled in a desiccator. In accordance with the above mentioned standard, the Repeated Immersion technique was applied. The samples of each type of composite materials were immersed into distilled water at 23 ± 1 °C for 2 and 24 h, and then removed from the water, patted dry and measured again. After 2, and respectively 24 h of immersion, both the thermal conductivity and resistance were measured for each sample.

Results and discussions

The morphology of the AACW-UPR composite materials was characterized by using a Scanning Electron Microscope (SEM, Quanta 200 FEI) equipped with a conventional tungsten electron source at 10 kV as accelerated voltage. Before SEM analysis, the fracture face of composites was sprayed with a thin gold alloy layer of 5 nm thickness using Sputter Coater System (SPI Supplies). SEM micrographs at different magnifications within the range 1000 and 20000X were captured.

Figure 4 shows the SEM cross-sectioned images of the composites obtained by addition the AACW particles to the epoxy resin matrix through the blending procedure. The microstructures tend to be more homogeneously along with increasing of AACW particles size added to the resin. Also, the particles distribution into the matrix indicated a well incorporation of them.

An increase of the surface roughness with increasing the grain size of AACW particles was observed (fig. 4a - 4c).

Figure 5 shows an important change of the surface texture at a higher resolution (20000X). Also, the porous appearance can be more clearly highlighted along with the particles size growth, as it is expected (fig. 5c). It can be noticed a relatively good homogeneous structure and good adhesion of coarse-grained AACW particles to the resin matrix.

Figure 6 shows the variation of water absorption capacity of the composite samples during immersion of 2 and 24 hours. Due to the capillarity the water absorption capacity depends on the porosity of the microstructure, the AACW particles size, the amount of resin contained in each sample, and the immersion time. The water absorption capacity also increased when the filler concentration increased. The sp6 sample (AACW particles size of 3-6 mm and resin of 50 vol.%) indicated the highest value for water absorption capacity. Instead, the lowest water absorption capacity was recorded for the sp3 sample (AACW particles size of 0.2-1 mm and resin of 70 vol.%). The sp1 sample in the absence of AACW particles led to a minimum value of water absorption capacity. The

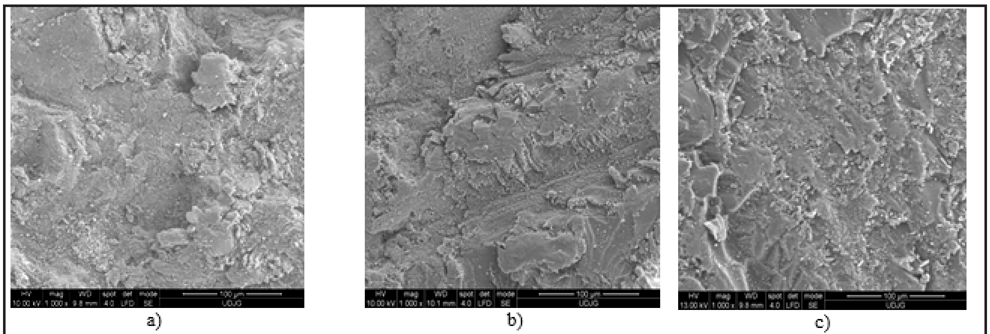

Fig.4. SEM images (fracture surface) of the AACW-UPR composite samples (100 µm scale bar):a) sp2,b) sp4,c) sp6

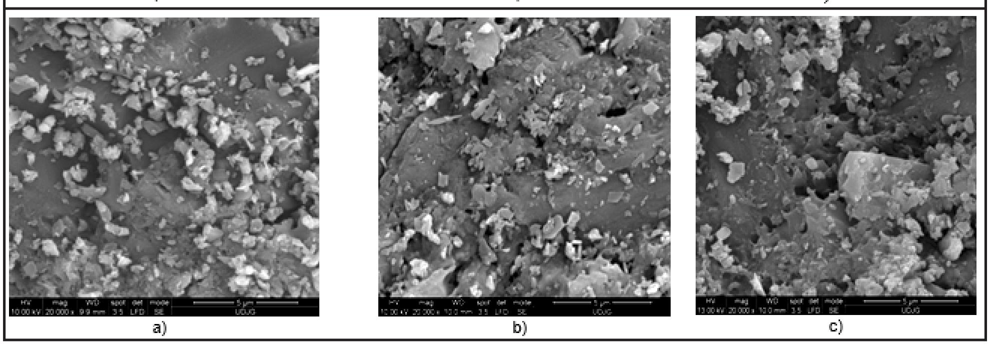

Fig.5. SEM images (fracture surface) of the AACW-UPR composite samples (5µm scale bar): a) sp3, b) sp5, c) sp7

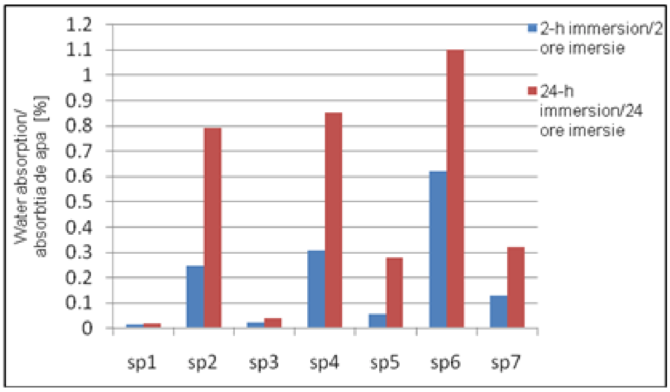

Fig.6. Water absorption of composite samples at 2 and 24 h immersion

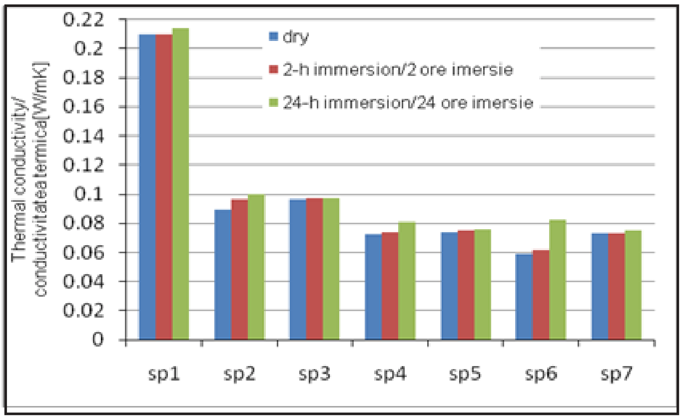

Fig.7. Thermal conductivity of composite samples in dry state and after 2 and 24 himmersion

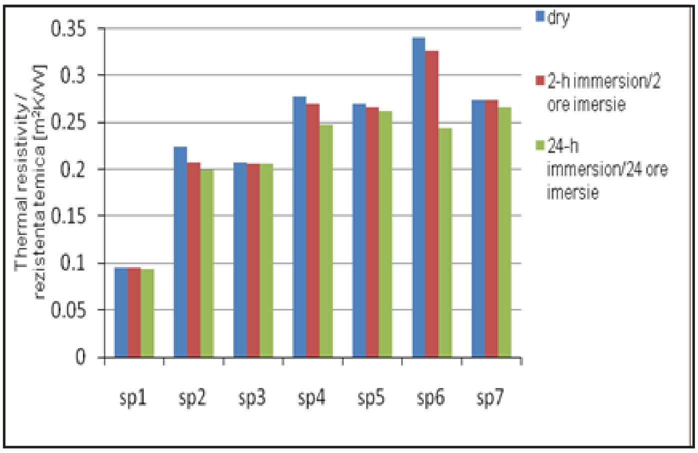

Fig.8. Thermal resistivity of composite samples in dry state and after 2 and 24 h immersion

excellent adhesion of the AACW particles to the resin matrix led to a decrease in water absorption capacity. As immersion time increases, there can be noticed an increase in water absorption capacity, especially for the samples contained AACW particles with the higher sizes. The results from the graph suggested a strong influence of the porosity on the water absorption capacity due to the AACW particles presence compared to sp1 sample (resin of 100 vol.%).

Figure 7 presents the variation of thermal conductivity for all 7 samples, both in the dry state, and after 2, and respectively 24 hours as immersion. The highest thermal conductivity was registered for the sp1 sample which does not contain AACW particles. The composite samples (AACW particles size of 3-6 mm and UPR of 50 vol.%) showed high thermal performance. Partial replacement of the UPR matrix with the AACW particles of different size led to a decrease in thermal conductivity. The increased porosity of the AACW particles leads to a decrease in the apparent density and also, causes a decrease in thermal conductivity. At the same time, high porosity of the AACW particles leads to a higher water absorption capacity over time, and so to a decrease in thermal performance. Therefore, an increase in thermal conductivity was observed for the samples with high UPR concentrations and reduced size of AACW particles. This aspect indicates that the pores inside the AACW particles are filled with resin.

Figure 8 shows a decrease in thermal resistance of the composites with increasing immersion time. Due to the excellent adhesion of the AACW particles to the UPR matrix, the water absorption capacity through capillarity decreased resulting in an increase in thermal resistance. The air contained in the pores of AACW particles leads to a growth in thermal resistance. In the dry state, the thermal resistance of the composite material increases by 54-72% after the partial replacement with AACW particles of different size, thus improving the properties as insulating material [17,18].

Conclusions

A hybrid particulate composite using the Autoclaved Aerated Concrete Waste (AACW) particles as filler and unsaturated polyester resin (UPR) as matrix has been developed.

The filler content and the particles size had considerable influence on thermal properties and water absorption capacity of the composites. The increase in the AACW particles content and their size led to an increase in thermal resistance by 54-72%.

The high amount of resin resulted in better adhesion between the matrix and the particles, so that the water absorption capacity decreased. If the resin fills out the pores inside the AACW particles than a reduction in thermal performance of the composite material can be notice.

The results presented in this paper highlighted the possibility to valorise the AAC waste through manufacture an environmentally friendly thermal insulating material.

References

1.*** Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain.

2. NARAYANAN, N., RAMAMURTHY, K., Structure and properties of aerated concrete: a review, Cement and Concrete Composites, 2000, 22(5), 321.

3. MITSUD, T.,SASAKI, K., ISHIDA,H., Phase evolution during autoclaving process of aerated concrete, Journal of the American Ceramic Society, 1992, 75(7), 1858.

4. RENMAN, G., RENMAN, A.,Sustainable use of crushed autoclaved concrete (CAAC) as a filter medium in wastewater purification, Proceedings of the 8th International conference on Sustainable management of waste and recycled materials in construction, Gothenburg, Sweden, 30 May - 1 June 2012.

5. SINICA, M.,SEZEMANAS, G., MIKULSKIS, D., KLIGYS, M., CESNAUSKAS, V., Investigation of Sorption Properties in Crushed Autoclaved Aerated Concrete Waste, Journal of Environmental Engineering and Landscape Management, 2012, 20(1), 67.

6. BOEHME, L., Chap-Yt–Recycled aerated concrete aggregates in traditional screed for flooring, Central Europe towards Sustainable Building 2013; 309.

7. BERGMANS, J., NIELSEN, P., BROOS, K., SNELLINGS, R., QUAGHEBEUR, M.,Recycling of autoclaved aerated concrete in screed and stabilized sand, Fifth International Conference on Construction Materials (CONMAT), Whistler, BC, Canada, August 2015.

8. BURUIANA, D.L., BORDEI, M., SANDU, I.G., CHIRCULESCU, A.I., SANDU, I.,. Studies on Grit Use in Asphalt Mixtures (II), Mat. Plast., **50**,no.2, 2013, p.113-118

9. BISCEGLIE, F.,GIGANTE, E.,BERGONZONI, M.,Utilization of waste Autoclaved Aerated Concrete as lighting material in the structure of a green roof, Construction and Building Materials, 2014, **69**, 351.

10. ARAYAPRANEE, W., REMPEL, G.L., Autoclaved aerated concrete waste (AACW): An alternative filler material for the natural rubber industry, Polymer Composites, 2014, **36**(11), 2030.

11. IPILAKYAA, T.D., DAGI, N.C., TULEUN, L.T.,Effects of Filler Content and Particle Size on the Mechanical Properties of Unsaturated Polyester Resin Reinforced with Rice Husk-Coconut Shell Particles, European Journal of Advances in Engineering and Technology, 2017, **4**(8), 637.

12. HARDINNAWIRDA, K., SITI RABIATULL AISHA, I., Effect of rice husks as filler in polymer matrix composites, Journal of Mechanical Engineering and Sciences, 2012, **2**, 181.

13. BARBUTA, M. HARJA, M., BABOR, D.,Concrete polymer with fly ash. Morphologic analysis based on scanning electron microscopic observations, Romanian Journal of Materials, 2011, **41**(3),301.

14. ***European Standard EN 12667:2002 - Thermal Performance of Building Materials and Products - Determination of Thermal Resistance by Means of Guarded Hot Plate and Heat Flow Meter Methods - Products of High and Medium Thermal Resistance.

15. ***ISO 8301:1991. Thermal Insulation - Determination of Steady-State Thermal Resistance and Related Properties - Heat Flow Meter Apparatus.

16. ***European Standard EN 933-1 - Test for geometrical properties of aggregates. Determination of particle size distribution. Sieving method.

17. BURUIANA, D.L., BORDEI, M., SANDU, I.G., CHIRCULESCU, A., SANDU,I., Recycling Waste Grit in Mix Asphalt, Mat. Plast., **50**,no.1, 2013, pp.36-39, 2013.

18. ***ASTM D570-98. Standard Test Method for Water Absorption of Plastics.

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