

# Possibility for obtaining cellular concretes based on serpentine materials

A A Orlov, N Ye Nikitenko, A A Gilevich

Department "Building Materials and Products", South Ural State University, 76, Lenin Avenue, Chelyabinsk 454080, Russia

E-mail: orlovaa@susu.ru

**Abstract.** The paper presents a complex of studies, aimed at obtaining cellular concrete based on unfired man-made magnesia material - serpentine. The test methods, applied in the paper, are shown. The properties of materials are described. A method of making cellular concrete based on serpentine and orthophosphoric acid was developed. In the course of a two-factor experiment, the key properties of cellular materials were defined. The nature of influence of the selected factors on the properties of compositions was identified. We found out the optimum amounts of orthophosphoric acid and the filler - ash, which will allow one to obtain cellular concrete that would be as good as gas concrete in terms of its physical and mechanical properties. The material, developed on the basis of serpentine and orthophosphoric acid, complies with the requirements of GOST 25485–89: density D 1,200, strength class B 10. A composition with such properties can be obtained in at  $ms+a/mo = 0.7 - 0.8$ ;  $ma/ms = 0.11 - 0.17$ . The heat conductivity coefficient of the selected composition:  $\lambda = 0.1647 \text{ W/(m}\cdot\text{°C)}$ . The nature of porosity of the materials being obtained was identified; the structure drawbacks and ways of their elimination were shown. The prospects of further research were identified.

## 1. Introduction

Cellular concrete is a porous artificial construction material that is obtained through the hardening of a preliminary bloated mixture of binding material, water and filler with a steam generator [1].

The application of cellular concretes in construction contributes toward the increase in the energy performance of buildings and structures, which is particularly topical for the Urals and Siberian regions [2].

Gas concrete is one of the variations of cellular concrete characterized by closed spherical pores uniformly distributed throughout the whole volume; the pores communicate with each other and are from 1 to 3 mm in diameter. Binding agents and special gas-forming agents are used in the production of this material [3].

A mineral binder that is becoming more and popular today is the magnesia binder [4]. Materials based on magnesia binders are characterized by top-class physical, mechanical and performance properties [5-10].

The traditional and most widespread method of obtaining construction binding agents is burning. However, burning requires a lot of materials, time and money. Also, burning produces hazardous substances (e.g.,  $\text{CO}_2$ ), which adversely affect the environment. This problem also applies to magnesia binding agents.



One of the means of addressing these problems lays in using unburned magnesia rock [11-15] and a special grouting fluid, e. g., orthophosphoric acid. Besides, many magnesia rocks interreact with the orthophosphoric acid very quickly releasing a lot of heat and gas (water vapor and carbon dioxide), which prevents material from being obtained on their basis [16]. Compositions based on natural magnesia silicate, e. g., serpentine, have an admissible rate of reaction. As a result of such a reaction, a material composed of magnesium phosphate, amorphous silica and unreacted serpentine is formed [15, 18].

Serpentine is a by-product of the mining of asbestos, brucite and many other magnesia rocks, which has not currently found its use in the industry and remains unclaimed waste that aggravates the ecological situation.

Serpentine has one specific feature: serpentine rocks gradually carbonize during the process of weathering [19]. This is the reason why the mixture of orthophosphoric acid and serpentine bloats, i.e., the reaction between the acid and magnesium carbonate produces carbon dioxide that bloats the mixture.

The above features of the ‘serpentine - orthophosphoric acid’ system ensure an opportunity for obtaining a cellular material on such a base.

## 2. Material and Methods

Materials 70% orthophosphoric acid (GOST 6552-80 Orthophosphoric acid. Specifications) was used. Finely ground serpentine ( $3\text{MgO}\cdot 2\text{SiO}_2\cdot 2\text{H}_2\text{O}$ ) from the Koncharsky field was used as the mineral powder in the binding composition (primary material: serpentine with admixed magnesite). The properties of serpentine are presented in the Table 1.

**Table 1.** Properties of serpentine.

Property	Value
Specific area, $\text{cm}^2/\text{g}$	4,000
Sieve residue 0.2, %	8.4
Sieve residue 0.08, %	86

Ash produced by the Troitskaya GRES power station was taken as the filler; the properties of the ash are presented in the Table 2.

**Table 2.** Properties of ash from Troitskaya GRES power station.

Property	Value
Bulk density when dry, $\text{kg}/\text{m}^3$	698
total sieve residue, %:	
< 0.16 mm	100
0.16-0.315 mm	65.2
0.315-0.63 mm	33.4
0.63-1.25 mm	15.0
1.25-2.5 mm	7.1
2.5-5 mm	3.9

The compression breaking strength of the hardened composition was determined according to GOST [20].

The average density was determined according to GOST 12730.1-78 [21].

The thermal conductivity was determined according to GOST 7076-99 [22].

The strength-density ratio was calculated according to the formula  $\text{SDR} = R_{\text{cmpr}}/\rho$ , where  $R_{\text{cmpr}}$  is the ultimate compression strength of the samples (MPa);  $\rho$  is the average density of the samples ( $\text{kg}/\text{m}^3$ ).

The manufactured samples underwent thermal treatment: 20°C (2 hours), 40°C (1 hour), 60°C (1 hour), 80°C (24 hours).

The thermal conditions, factors and their scope were determined in the course of preliminary experiments.

**3. Results and discussion**

A two-factor experiment was planned and conducted in order to study the physical and mechanical properties of the cellular material based on serpentine and orthophosphoric acid: the first factor was the ‘mass of serpentine and ash to mass of 70% orthophosphoric acid’ ratio, and the second factor was the ‘mass of ash to mass of serpentine’ ratio. The responses were the strength, density, and strength-density ratio.

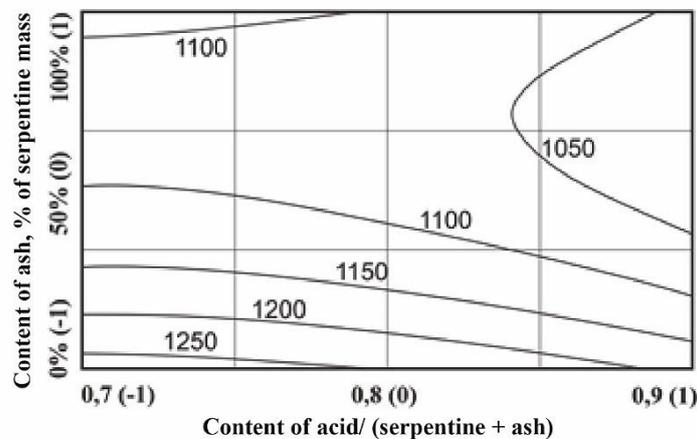
The matrix chart and responses are presented in the Table 3.

**Table 3.** Matrix chart and responses.

Code value of factor 1	Code value of factor 2	$m_{s+a}/m_o$	$m_a/m_s, \%$	$m_s, g$	$m_a, g$	$m_o, g$	Responses		
							$\rho, g/cm^3$	R, MPa	SDR
-1	-1	0.7	-	1,200	0	840	1.38	13.3	9.61
0	-1	0.8	-	1,200	0	960	1.37	13.6	9.91
1	-1	0.9	-	1,200	0	1,080	1.33	8.46	6.35
-1	0	0.7	50	800	400	840	1.24	7.98	6.43
0	0	0.8	50	800	400	960	1.23	7.06	5.73
1	0	0.9	50	800	400	1,080	1.06	3.54	3.33
-1	1	0.7	100	600	600	840	1.22	6.18	5.07
0	1	0.8	100	600	600	960	1.17	4.92	4.21
1	1	0.9	100	600	600	1,080	1.19	3.53	2.97

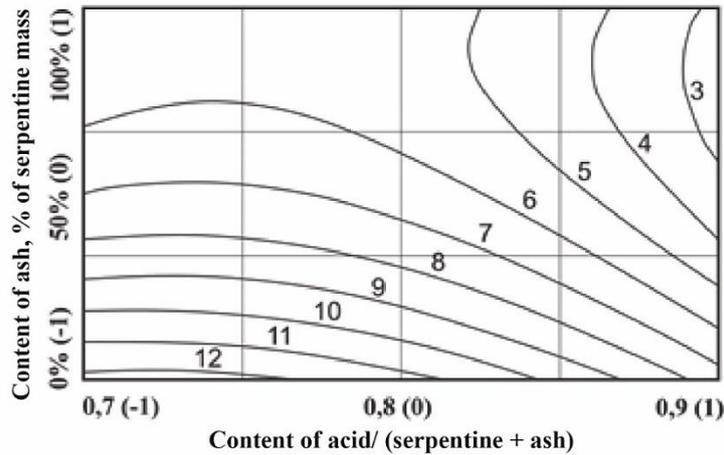
\*  $m_{s+a}$  – mass of serpentine and ash.  
 $m_o$  – mass of orthophosphoric acid.  
 $m_a$  – mass of ash.  
 $m_s$  – mass of serpentine.

After the obtained results (table 3) were processed, graphs shown in the figures 1 – 3 were plotted.



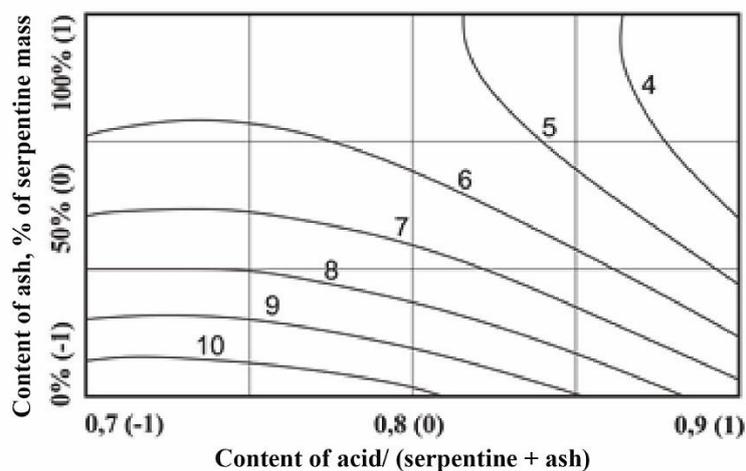
**Figure 1.** Changes in the composition density with respect to variable factors,  $kg/m^3$ .

As we know, the density of gas concrete is largely influenced by the amount of gas being released and the viscosity of the blend. According to the variations shown in the Figure 1, an increase in the amount of acid in relation to serpentine leads to a decrease in the composition density, since the amount of gas being released increases, and the viscosity of the blend decreases. An increase in the amount of filler leads to a decrease in the composition density due to (1) the low density of ash and (2) a decrease in the viscosity of the blend. The viscosity decreases because the specific surface area of ash is bigger than that of serpentine.



**Figure 2.** Changes in the composition strength with respect to variable factors, MPa

According to the present figure, one can observe similarities between the lines depicting the changes in the strength with respect to variable factors and the density graph. Similarly, it can be pointed out that the greatest strength is achieved with the minimal content of the ash filler and with the minimal amount of acid in the hardening composition. Therefore, the strength of porous composition within this scope of factor variation directly depends on the material density.

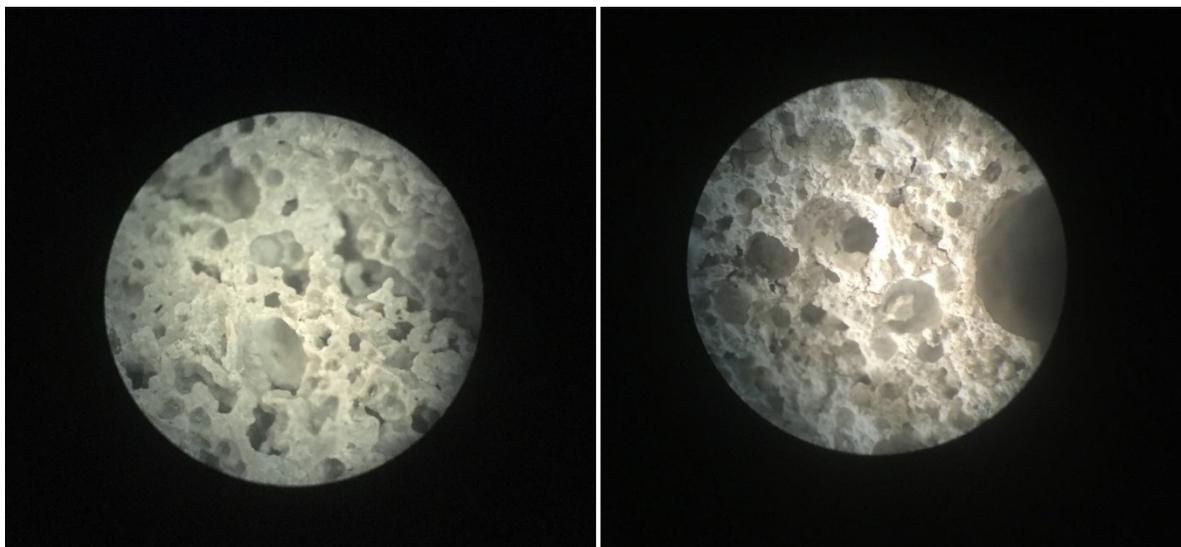


**Figure 3.** Changes in the strength-density ratio with respect to variable factors.

The graph showing the changes in the strength-density ratio is also similar to the previously analyzed graphs in terms of baseline positions.

The best SDR is present in the area with the minimal amount of acid and the minimal amount of ash. The variations show that the SDR decreases when the density decreases and the porosity increases, which means that the strength of the composition decreases faster than its density.

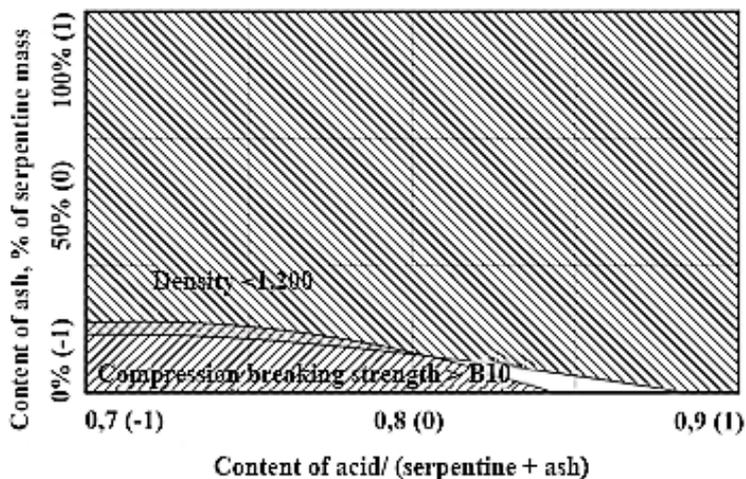
The Figure 4 shows examples of the cellular system ‘serpentine - orthophosphoric acid.’



**Figure 4.** Porosity of the ‘serpentine - orthophosphoric acid’ system.

According to the figure 4, one can see that the pores that are being formed are of irregular shape; there are cracks that have appeared due to gas formation in the hardening structure. I.e., the formation, densification and hardening of the present composition are not preferable.

In order to determine the scope of variable factors that will allow us to obtain a material that would meet the requirements of GOST 25485–89, let us put the obtained graphs (figure 1 and 2) on top of each other [23]. The results are presented in the figure 5.



**Figure 5.** Selecting the ideal proportions of the serpentine-phosphate composition.

The Figure 5 shows the area of factor variation in which the material based on serpentine and orthophosphoric acid meets the requirements of GOST 25485–89: density 1,200, strength class B 10. A composition with such properties can be obtained within the scope of:  $ms+a/mo = 0.7 - 0.8$ ;  $ma/ms$

= 0.11 – 0.17. One can suppose that these proportions might change if a serpentine rock of another mineral composition is used.

The heat conductivity coefficient of the selected composition is  $\lambda = 0,1647 \text{ W/(m}\cdot\text{°C)}$ .

#### 4. Summary

In the course of the conducted work, it was determined that one can obtain cellular materials from serpentine and orthophosphoric acid, provided the required formation, densification and hardening parameters have been selected for such a system. This will allow significantly to increase the properties of the material being developed.

Since the composition being developed consists of magnesium phosphates, it can be an effective fire- and heat-proof material [24].

Therefore, obtaining cellular fire-proof materials based on serpentine and orthophosphoric acid has perspectives for further research.

#### Reference

- [1] Gladkov D I, Suleymanova L A, Kalashnikov A V 1999 New technology of cellular concrete products *Build. mater.* **7** pp 26–27
- [2] Kiyanev A V 2017 Improving Energy Efficiency of Buildings in the Urals *IOP Conf. Ser.: Mater. Sci. and Eng.* **262(1)** 012068
- [3] Volzhensky A V, Chistov Yu D, Karpova T A, Iskhakova A A 1990 Technology and properties of non-autoclaved aerated concrete products with normative humidity and thermal conductivity *Build. mater.* **11** pp 7–8
- [4] Averina G F, Katasonova A V, Zimich V V and Chernykh T N 2016 Increase of water resistance of magnesia stone for hardening filling mixtures from man-made dolomites *Bull. of South Ural State University. Series: Constr. and arch.* **16 (2)** pp 28–32
- [5] Kiyanev A V 2017 Using Mortar Mixing Pump for Magnesia Mortars Preparing and Transporting *IOP Conf. Series: Mater. Sci. and Eng.* **262(1)** 012067
- [6] Kiyanev A V 2017 Technological Parameters of Magnesia Mortars *Procedia Eng.* **206** pp 826–830
- [7] Kiyanev A V 2016 Resource-saving Construction Technologies *Procedia Eng.* **150** pp 2124–2127
- [8] Kiyanev A V 2016 The negative temperature impact on the hardening of magnesia composites *Mater. Sci. Forum* **843** pp 91–95
- [9] Mitin N A 2016 Waterproof Magnesia Binder for Composite Materials [Electronic resource] *Key Eng. Mater.: Sci. Jour.* **712** pp 182–187
- [10] Mitina A A, Mitina N A 2014 Advantages and prospects of magnesia cements [Electronic resource] *Perspective materials in engineering and construction (PMTC-2014): materials of the International Scientific Conference of Young Scientists* pp 654–657
- [11] Chernova E A 2011 On the Application of Phosphate Binders in Compositions with Carbonate-Containing Waste from Industry *XVII International Scientific and Practical Conference "Modern Technologies and Technologies"* (Tomsk: Tomsk Polytechnic University) p 480
- [12] Nurbaturov K A, Rodionova A A, Yugay V A, Kan A V 2007 An effective way to polish silicate systems for the production of heat-insulating heat-resistant materials *Proceedings of the sci. and tech. soc. KAHAK* **1(16)** p 102
- [13] Hall D A, Stevens R, El-Jazairi B 2001 The effect of retarders on the microstructure and mechanical properties of magnesia-phosphate cement mortar *Cement and Concrete Research* **31(3)** pp 455–465
- [14] Mitin N A 2016 Prospects for the use of magnesian rocks [Electronic resource] *Problems of geology and mineral exploration: Works of the XXth International Academic MA Ussov Symposium of students and young scientists dedicated to the 120th anniversary of the founding of Tomsk Polytechnic University* **2** pp 641–642

- [15] Sudakas L G 2008 Phosphate binders (St. Petersburg: RIA "Quintet") p 260
- [16] Sokolova S V 2004 Influence of the structural and energy characteristics of metal hydroxides on their chemical binding to orthophosphoric acid in order to obtain phosphate binders for heat-resistant concrete *Refract. and tech. ceram* **9** pp 29–31
- [17] Orlov A A, Chernykh T N 2016 Research of water resistance and heat resistance of magnesium phosphate cements *Procedia Eng.* **150** pp 1623–1626
- [18] Belov M A, Debin N V, Konosov Yu B 1975 *The practice of enriching asbestos ores* (Moscow: Nedra) p 224
- [19] State Standard 10180–2012 *Concrete. Methods for determining the strength of control samples* (Moscow, Standartinform) p 31
- [20] State Standard 12730.1–78 *Concretes. Methods for determining the density* (Moscow, Standartinform) p 6
- [21] State Standard 7076–99 *Materials and products for construction. Method for the determination of thermal conductivity and thermal resistance for a stationary thermal regime* (Moscow, Standartinform) p 12
- [22] State Standard 25485–1989 *Concrete is cellular. Technical conditions* (Moscow, Standartinform) p 17
- [23] Abyzov VA 2016 Lightweight refractory based on aluminum-magnesium-phosphate binder *Procedia eng.* **150** pp 1440–1445