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COMPOSITE MATERIALS WITH CERAMIC AND METALLIC PARTICLES REINFORCED CLAY MATRIX

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Abstract: *The paper includes a research on the obtaining characteristics and mechanical properties of the composites with Al_2O_3, SiC, Cu, Al and Fe particles reinforced clay and bentonite ceramic matrix. Were obtained four types of composite materials namely: Al_2O_3 and SiC particles reinforced clay matrix, Al_2O_3 and SiC particles reinforced bentonite matrix, Al_2O_3, SiC, Cu, Al and Fe particles reinforced clay matrix and Al_2O_3, SiC, Cu, Al and Fe particles reinforced bentonite matrix. The composites prepared were subjected to a study to analyze the mechanical properties (compressive resistance).*

Key words: *Clay, Al_2O_3, SiC, metallic particles, compressive resistance.*

1. Introduction

The composite material is composed of a basic material, the matrix, in which the additional material is dispersed in the form of particles or fibers [11, 8, 2, 7].

The advantageous characteristics of ceramic materials include low density, high abrasive toughness, hardness, and rigidity. Nevertheless, monolithic ceramics main drawback is their low fracture toughness [11, 8, 2, 7]. Thence, many studies have been conducted with the aim of addressing this shortcoming [8, 1, 2, 3, 9, 10, 13].

Particulate ceramic matrix composites have been developed to achieve damage tolerant fracture behaviour while maintaining other advantages of monolithic ceramics. It is established that particulate ceramic matrix composites are among those promising materials for high performance applications under severe environment such as high temperature. Particles reinforced ceramic composites are used as functional components in brake assembly, furnace materials, energy conversion systems, gas turbines, heat engines etc. [13].

Clay is a natural inorganic binder consisting of oxides, hydroxides, carbonates, feldspars, mica etc. impure kaolin. Depending on the amount of water absorbed, the clay swells, acquires bonding properties. Bentonites are a variety of clays with a high montmorillonite content (over 70%). Due to the high water adsorption and ion exchange capacities, bentonite can be used in many different technological applications, e.g. catalysts in chemical and oil processing industries, admixtures for plastification and manipulation of viscosity of ceramic pastes or sealing materials for civil and environmental engineering [6].

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Delage et al. [5] studied the obtaining of bentonite matrix composites by conventional methods, and drying techniques induce significant capillary forces which may lead to drying shrinkage artifacts. Chenu and Tessier [4] and Smart et al. [12], studied the obtaining these types of composites by cryo-preparation techniques freezing under liquid nitrogen or propane atmosphere for samples with a maximum thickness of 5 µm.

The paper focuses on the synthesis and characterisation of a promising ceramic and metallic particles reinforced ceramic matrix composite.

2. Materials and Techniques

For matrix we used two types of materials: clay (37% Al_2O_3, max. 2,2 % Fe_2O_3, max. 60.8% SiO_2) and bentonite (53% montmorillonit, max. 2,2 % Fe_2O_3, max. 60.8% SiO_2). Reinforcing materials used are Al_2O_3 and SiC ceramic particles and Cu, Al and Fe metallic particles. The proportions of the components used to perform the samples are shown in Tables 1, 2, 3 and 4.

Firstly, were made composites with ceramic matrix and reinforcement components (Table 1). Then, to the same amounts were added Cu (Table 2), Al (Table 3) and Fe (Table 4) metallic particle to obtain the other types of composite.

For achieving the composites, the quantitative dosed materials were introduced in a container according to Tables 1-4, where for homogenization they were mixed in a dry state. After 5 minutes of mixing, the material thus prepared was introduced into a metallic mold where it was pressed to the test machine. The mold was sprayed with a mold release agent to prevent adhesion of composites and also to ensure smooth sample surface.

Composites with Al_2O_3 and SiC particles reinforced powders matrix Table 1

Sample number	**Components**				**Compaction pressure, [KN]**	**Sintering regime**	
	Clay		**SiC**			**Temp., [°C]**	**Time at sintering temp., [min.]**
	[%]	**[g]**	**[%]**	**[g]**			
111	94.4	17	56	1	15	1000	60
112	88.9	16	11.1	2			
113	83.3	15	16.7	3			
	Clay		**[Al_2O_3]**		17		
121	94.4	17	5.6	1			
122	88.9	16	11.1	2			
123	83.3	15	16.7	3			
	Bentonite		**SiC**		15	1250	
211	94.4	17	5.6	1			
212	88.9	16	11.1	2			
213	83.3	15	16.7	3			
	Bentonite		**Al_2O_3**		19		
221	94.4	17	5.6	1			
222	88.9	16	11.1	2			
223	83.3	15	16.7	3			

Composites with Al_2O_3, SiC and Cu particles reinforced powders matrix Table 2

<table>
<tr><th rowspan="3">Sample number</th><th colspan="6">Components</th><th rowspan="3">Compaction pressure, [KN]</th><th colspan="2">Sintering regime</th></tr>
<tr><th colspan="2">Clay</th><th colspan="2">SiC</th><th colspan="2">Cu</th><th rowspan="2">Temp., [°C]</th><th rowspan="2">Time at sintering temp., [min.]</th></tr>
<tr><th>[%]</th><th>[g]</th><th>[%]</th><th>[g]</th><th>[%]</th><th>[g]</th></tr>
<tr><td>111 Cu</td><td>85</td><td>17</td><td>5</td><td>1</td><td>10</td><td>2</td><td>20</td><td rowspan="7">1000</td><td rowspan="15">60</td></tr>
<tr><td>112 Cu</td><td>80</td><td>16</td><td>10</td><td>2</td><td>10</td><td>2</td><td>20</td></tr>
<tr><td>113 Cu</td><td>75</td><td>15</td><td>15</td><td>3</td><td>10</td><td>2</td><td>17</td></tr>
<tr><td></td><td colspan="2">Clay</td><td colspan="2">Al_2O_3</td><td></td><td></td><td></td></tr>
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<tr><td></td><td colspan="2">Bentonite</td><td colspan="2">SiC</td><td></td><td></td><td rowspan="4">17</td><td rowspan="8">1250</td></tr>
<tr><td>211 Cu</td><td>85</td><td>17</td><td>5</td><td>1</td><td>10</td><td>2</td></tr>
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<tr><td>221 Cu</td><td>85</td><td>17</td><td>5</td><td>1</td><td>10</td><td>2</td><td>15</td></tr>
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<tr><td>223 Cu</td><td>75</td><td>15</td><td>15</td><td>3</td><td>10</td><td>2</td><td>16</td></tr>
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Composites with Al_2O_3, SiC and Al particles reinforced powders matrix Table 3

<table>
<tr><th rowspan="3">Sample number</th><th colspan="6">Components</th><th rowspan="3">Compaction pressure, [KN]</th><th colspan="2">Sintering regime</th></tr>
<tr><th colspan="2">Clay</th><th colspan="2">SiC</th><th colspan="2">Al</th><th rowspan="2">Temp., [°C]</th><th rowspan="2">Time at sintering temp., [min.]</th></tr>
<tr><th>[%]</th><th>[g]</th><th>[%]</th><th>[g]</th><th>[%]</th><th>[g]</th></tr>
<tr><td>111 Al</td><td>85</td><td>17</td><td>5</td><td>1</td><td>10</td><td>2</td><td rowspan="3">20</td><td rowspan="7">1000</td><td rowspan="15">60</td></tr>
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<tr><td></td><td colspan="2">Clay</td><td colspan="2">Al_2O_3</td><td></td><td></td><td></td></tr>
<tr><td>121 Al</td><td>85</td><td>17</td><td>5</td><td>1</td><td>10</td><td>2</td><td rowspan="3">20</td></tr>
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<tr><td></td><td colspan="2">Bentonite</td><td colspan="2">Al_2O_3</td><td></td><td></td><td></td></tr>
<tr><td>221 Al</td><td>85</td><td>17</td><td>5</td><td>1</td><td>10</td><td>2</td><td>14</td></tr>
<tr><td>222 Al</td><td>80</td><td>16</td><td>10</td><td>2</td><td>10</td><td>2</td><td>17</td></tr>
<tr><td>223 Al</td><td>75</td><td>15</td><td>15</td><td>3</td><td>10</td><td>2</td><td>16</td></tr>
</table>

The samples thus obtained were sintered in a Nabertherm furnace according to the temperatures in the Tables 1, 2, 3 and 4. After sintering, the obtained samples were subjected to a study to specify the compressive strength.

Composites with SiC, Al_2O_3, and Fe particles reinforced powders matrix Table 4

Sample number	Components						Compaction pressure, [KN]	Sintering regime	
	Clay		SiC		Al			Temp., [°C]	Time at sintering temp., [min.]
	[%]	[g]	[%]	[g]	[%]	[g]			
111 Fe	85	17	5	1	10	2	20	1000	60
112 Fe	80	16	10	2	10	2			
113 Fe	75	15	15	3	10	2			
	Clay		**Al_2O_3**				20		
121 Fe	85	17	5	1	10	2			
122 Fe	80	16	10	2	10	2			
123 Fe	75	15	15	3	10	2			
	Bentonite		**SiC**				17	1250	
211 Fe	85	17	5	1	10	2			
212 Fe	80	16	10	2	10	2			
213 Fe	75	15	15	3	10	2			
	Bentonite		**Al_2O_3**						
221 Fe	85	17	5	1	10	2	15		
222 Fe	80	16	10	2	10	2	18		
223 Fe	75	15	15	3	10	2	18		

Compressive strength was performed on the universal testing machine. The test are cylindrical (diameters: 15-16 mm and heights 11-15 mm). From the machine test chart, were extracted the specific values which were used to interpret the results. A minimum of 3 tests were performed for each type of composite sample. Then, the mean for the values obtained from the determinations are calculated (Tables 5-8, the diagrams of Figures 1-4).

3. Results and Discussion

The values arithmetic mean for the measurements extracted from the compressive test charts are shown in Tables 5-8. For a better interpretation of experimental results, for each type of composites made, compressive strength dependence graphs were constructed depending on the proportions modification of the used components (Figures 1-4).

Compressive test results for SiC, Al_2O_3 and Cu particles reinforced powders matrix Table 5

Sample number	F_{bc}, [KN]	F_{sc}, [KN]	F_{pc}, [KN]	R_{bc}, [MPa]	R_{sc}, [MPa]	R_{pc}, [MPa]	E_c, [GPa]
111 Cu	4.08	2.63	3.92	20	13	19	1.74
112 Cu	4.83	4.79	4.54	24	25	22	1.28
113 Cu	8	1.38	4.91	40	8	24	10.34
121 Cu	3.71	1.52	3.53	19	8	18	1.38
122 Cu	3.86	2.47	2.69	20	13	14	1.56
123 Cu	7.54	1.62	7.1	38	8	35	3.37

F_{bc} - maximum force; F_{sc} - breaking force at compression; F_{pc} - initial force at compression force; R_{bc} - material strength at the maximum force; R_{sc} - material strength before breaking; R_{pc} - initial strength material at compression; E_c - Young's modulus at compression module.

Compressive test results for SiC si Al_2O_3 particles reinforced powders matrix Table 6

Sample number	F_{bc}, [KN]	F_{sc}, [KN]	F_{pc}, [KN]	R_{bc}, [MPa]	R_{sc}, [MPa]	R_{pc}, [MPa]	E_c, [GPa]
111	8.93	8.86	8.85	48	48	48	3.99
112	7.95	/	5.25	42	/	28	/
113	7.42	/	7.34	39	/	39	3.25
121	9.89	9.41	9.54	53	51	51	4.23
122	7.35	7.25	7.21	39	38	38	3.43
123	7.08	6.87	4.10	37	36	21	0.6
211	20.35	19.78	18.89	111	105	100	6.38
212	19.61	/	18.60	104	/	99	6.68
213	18.80	/	16.57	100	/	88	5.94
221	24.85	24.72	23.96	135	134	130	7.45
222	20.72	20.12	19.18	111	108	103	6.45
223	17.14	17.08	16.24	90	89	85	5.72

Compressive test results for SiC, Al_2O_3 and Al particles reinforced powders matrix Table 7

Sample number	F_{bc}, [KN]	F_{sc}, [KN]	F_{pc}, [KN]	R_{bc}, [MPa]	R_{sc}, [MPa]	R_{pc}, [MPa]	E_c, [GPa]
111 Al	8.27	1.85	6.87	41	9	34	6.8
112 Al	10.65	6.2	10.25	53	31	51	3.01
113 Al	11.19	1.87	6.76	56	9	34	3.43
121 Al	8.74	2.88	7.66	43	14	38	2.77
122 Al	10.79	2.22	9.91	55	11	51	5.02
123 Al	11.16	2.28	10.12	62	13	57	4.03
211 Al	10.6	10.84	10.22	52	52	50	4.6
212 Al	18.14	5.25	16.97	88	25	82	5.09
213 Al	19.34	4.52	18.79	96	22	93	6.32
221 Al	11.87	11.86	10.89	58	58	53	3.19
222 Al	12.27	12.27	12.06	60	60	59	4.38
223 Al	13.35	9.09	13.24	66	65	65	4.59

Compressive test results for SiC, Al_2O_3 and Fe particles reinforced powders matrix Table 8

Sample number	F_{bc}, [KN]	F_{sc}, [KN]	F_{pc}, [KN]	R_{bc}, [MPa]	R_{sc}, [MPa]	R_{pc}, [MPa]	E_c, [GPa]
111 Fe	6.88	3.96	6.71	34	19	33	2.55
112 Fe	8.49	3.36	7.7	42	20	39	1.8
113 Fe	9.87	2.56	9.58	55	45	55	2.54
121 Fe	5.22	1.23	4.68	26	7	23	2.67
122 Fe	6.62	0.72	6.12	33	4	30	2.88
123 Fe	15.12	3.37	13.77	75	17	69	5.05
211 Fe	10.88	1.84	7.77	56	10	40	2.03
212 Fe	13.46	9.25	13.22	68	13	66	3.56
213 Fe	20.45	5.13	19.21	99	23	85	5.66
221 Fe	13.29	2.98	10.64	69	15	55	3.61
222 Fe	14.76	2.24	11.89	77	12	62	2.15
223 Fe	27.55	15.38	26.86	141	78	137	8.66

In the following figures are represented the compressive strength variation depending on the granular material content.

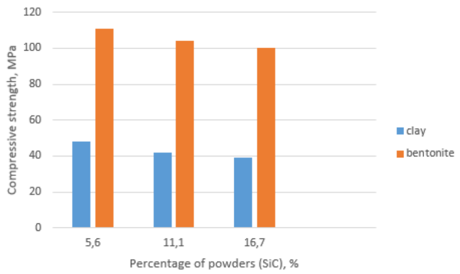

Fig. 1. *Compressive strength variation of clay and bentonite composites depending on the content of SiC*

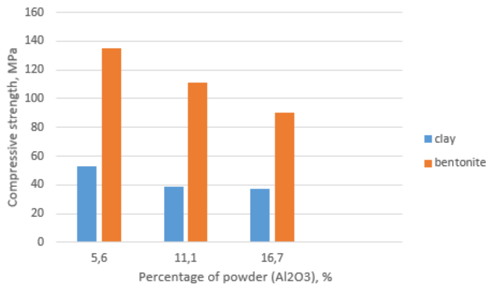

Fig. 2. *Compressive strength variation of clay and bentonite composites depending on the content of Al_2O_3*

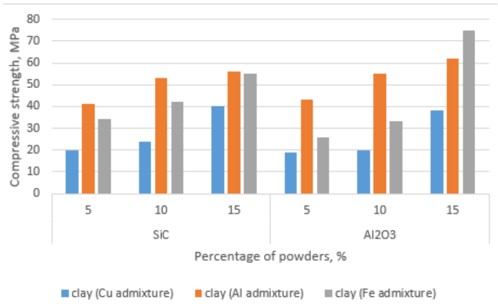

Fig. 3. *Compressive strength variation of clay composites with 10% Cu, Fe, Al admixture*

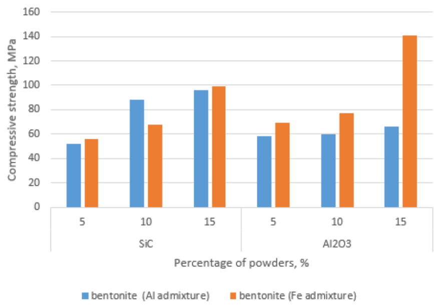

Fig. 4. *Compressive strength variation of bentonite composites with 10% Fe, Al admixture*

Both in the case of SiC and Al_2O_3 particles reinforced clay matrix and in the case of SiC and Al_2O_3 particles reinforced bentonite matrix the compressive strength decreases with increasing the percentage of granular material (SiC and Al_2O_3), (Figures 1 and 2). This type of variation can be explained in correlation with the obtaining composites of mixed, pressed and dry particles. Also taking into account the fact that both the SiC and the Al_2O_3 are introduced as impurities in the matrix, without to achieve to sintering the monolithic structure of the composite.

The behavior changes radically by adding the metallic particles to the composite. In this time, compressive strengths increase with the increasing of SiC and Al_2O_3 particles (Figures 1, 2, 3 and 4). Influences are specific to each type of composite.

For SiC particles reinforced clay matrix composites the Cu, Fe and Al admixture cause, in this order, increases of compressive strengths. In the case of Al_2O_3 particles reinforced clay matrix is found the same type of arrangement. At the same time, the admixture of metallic particles has different effects for the same type of composite materials. In the

Cu admixture case is obtained a compressive strengths higher for SiC particle reinforced matrix composite than Al_2O_3 particle reinforced matrix composite. In the case of Al and Fe is obtained a compressive strengths higher for Al_2O_3 particle reinforced matrix composite.

The SiC, Al_2O_3 and Cu particles reinforced bentonite matrix composite have not been tested to resistance because the Cu has created slagging reactions to sintering. For these composites with Al and Fe admixture the compressive strength increases in this order also. In each case, the compressive strengths were higher for Al_2O_3 particles composites than for SiC particles composites.

The positive effects of the metallic particles admixture on compressive strength can be attributed to different behavior of the materials in terms of taking over the test loads. The metallic particles give a high elastic component.

The highest values of compressive strength were obtained for Al_2O_3 and Fe particles reinforced bentonite matrix composites.

4. Conclusion

The SiC and Al_2O_3 ceramic powders addition to clay and bentonite matrix composites lead to compressive strength lower.

The addition of metallic particles into composites changes completely this type of behavior. The compressive strength increases with the SiC and Al_2O_3 quantities of composite. The effect is stronger for SiC when adding Cu and Al_2O_3 to Al and Fe.

In the case of composites with SiC particles better results are obtained to Cu adding and in the case of composites with Al_2O_3 particles better results are obtained to Al and Fe adding.

For clay matrix composites, the effect of metallic particles is in increasing order Cu↗, Fe↗, Al↗. In the case of bentonite matrix composites the order is Al, Fe. The highest compressive strength was obtained for bentonite matrix composites with 15% Al_2O_3 and 10% Fe (141 MP). In all cases, bentonite matrix composites have higher compressive strength than clay matrix composites.

Acknowledgements

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