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The moisture content and mechanical properties of ceramic masses

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Abstract

The material strength of different ceramic masses in dependence on their moisture content is presented in this paper. The experiments were carried out by using a universal strength machine. The compressive strength tests were performed for three different materials widely used in ceramic industry: KOC kaolin clay, illite clay and electrotechnical porcelain mass C130. In addition one dimensional tensile tests were carried out for kaolin clay to compare tensile and compressive strength.
Keywords: Compressive strength, Tensile strength, Yield stress, Ceramic mass

ZAWARTOŚĆ WILGOCI A WŁAŚCIWOŚCI MECHANICZNE MAS CERAMICZNYCH

W pracy przedstawiono zależność wytrzymałości materiałów dla różnych mas ceramicznych w zależności od zawartości wilgoci. Eksperymenty przeprowadzono na uniwersalnej maszynie wytrzymałościowej. Wytrzymałość na ściskanie badano dla trzech różnych mas ceramicznych szeroko stosowanych w przemyśle ceramicznym: kaolinu KOC, gliny i elektroporcelanowej masy C130. Dodatkowo przeprowadzono testy jednoosiowego rozciągania dla kaolinu KOC w celu porównania wytrzymałości na ściskanie oraz rozciąganie.
Słowa kluczowe: wytrzymalość na ściskanie, wytrzymałość na rozciąganie, granica plastyczności, masa ceramiczna

1. Introduction

Knowledge of ceramic masses strength is required in many areas of engineering and science. Drying is one of the stages in technological manufacturing of ceramic products where this knowledge is useful. To prevent damage of products during drying (deformations, part-through and through-the-thickness cracks) one can use computer calculations to choose proper temperature and humidity of drying medium. But the knowledge of material strength and other material coefficients is necessary to perform such computer simulations [1, 2, 4, 9].

Strength of dried materials evidently depends on moisture content and changes during the drying process [1, 3, 5, 8, 9]. An experimental investigation of moisture content influence on material strength of selected porous materials is presented in this paper. The results of two kinds of strength tests are analyzed: tensile and compressive ones.

2. Materials and methods

Three types of porous materials were investigated in this paper: KOC kaolin clay, illite clay and electrotechnical porcelain mass C130. All of them are widely applied in ceramic industry [11]. KOC Kaolin clay from Surmin-Kaolin SA Company is used in manufacturing sanitaryware and tableware. It provides strength and plasticity in the shaping of these products and reduces the amount of pyroplastic deformation in the process of firing. Another tested material is typical regional illite clay widely used to produce bricks and domestic goods in local factories. The last of analyzed materials is electrotechnical porcelain. There are three types of ceramic masses used in manufacturing electric isolators in Poland: C110, C120 and C130. The most advanced of them is electrotechnical porcelain mass C130 and is used for high-voltage isolators explored in extreme conditions.

The influence of moisture content on material strength was studied for tensile and compressive forces (Fig. 1). Each of materials was analyzed in one-dimensional compressive tests. Additionally one-dimensional tensile tests were carried out for the kaolin clay. All of the tests were performed by using a universal strength measuring machine Koegel FGP 7/18 – 1000. The studies always were carried out for the constant (tensile or compressive) force increment: 1N/s.

To prepare ceramic masses for experiments some water was added to achieve approximately their initial moisture content. Each mass was homogenized and stored in closed box for 48 hours to unify the moisture distribution in

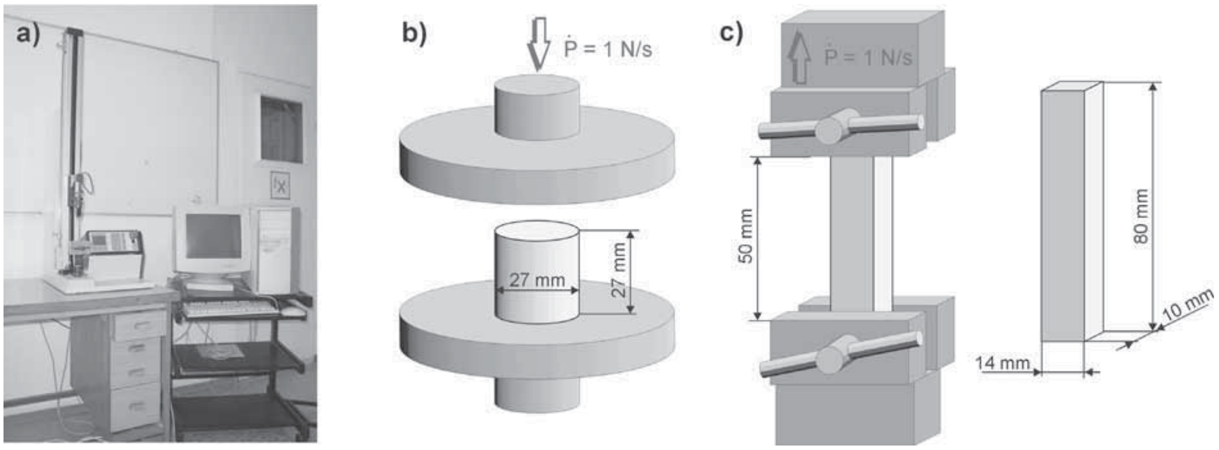

Fig. 1. a) Strength-measuring instrument Koegel FPG 7/18-1000, b) one-dimensional compressive test, c) one-dimensional tensile test and dimensions of the sample.

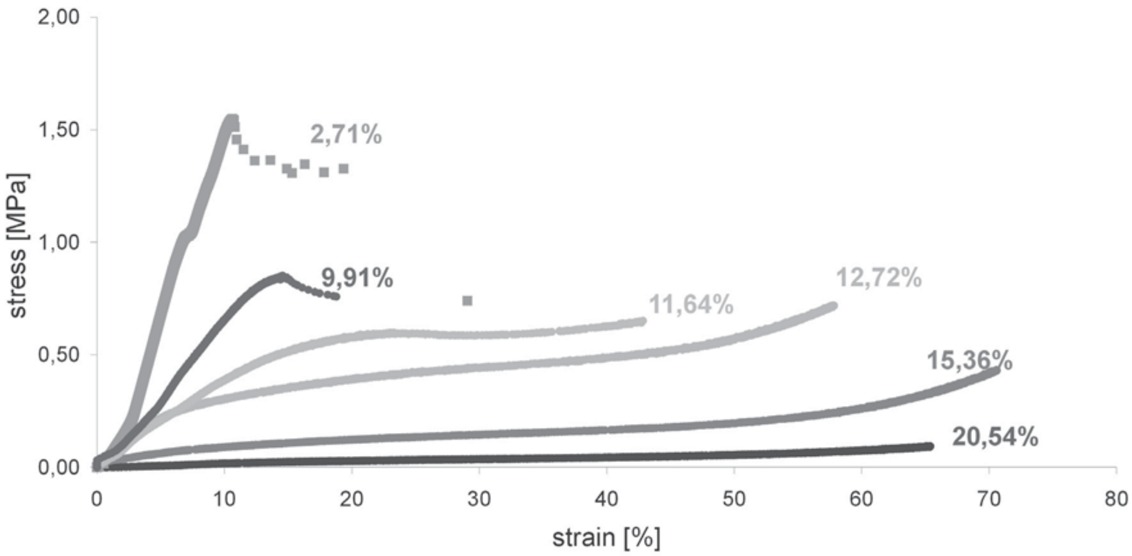

Fig. 2. Compressive test: stress-strain relation obtained for illite clay samples.

the whole material. The mass obtained in such a way was used to mold cylindrically shaped specimens (diameter d = 0.027 m and the same height h = 0.027 m) for compressive tests. The samples of all analyzed materials were extruded. The specimens made from kaolin clay used in the tensile tests were casted in a gypsum form. They were prepared in 80 mm length rods with the rectangular cross--section of 10 mm $\times$16 mm (b$\times$h).

Because of the wide range of moisture content of analyzed materials the samples had to be prepared in three different ways depending on their moisture content. The samples with high moisture content (*e.g.* for kaolin clay above 30%) were used in the tests right after moulding. The samples with the moisture content between the material equilibrium moisture content and the best moulding moisture content were moulded at the best moulding moisture content. They were slowly dried then to the demanded moisture content, packed and stored for 24 hours to unify their moisture content. Thereafter the samples were ready to use in experiments. The materials below their equilibrium moisture content were prepared as follows: the moulded samples were dried in the open air conditions and they were over dried in a laboratory drier, packed and after 24 hours ready to use in the tests.

To determine the actual moisture content of each sample, they were weighted after every test, dried to the constant mass and then weighted again.

3. Results

One can acquire the stress-strain relation directly from the performed strength tests. As an example the results from the compressive tests are presented in Fig. 2, showing the stress-strain curves for the samples of the chosen moisture content and made from illite clay.

For the sample with the lowest moisture content (2.71%) one can observe first brittle crash at about 1.1 MPa during the test and then the proper material strength is noticed near 1.6 MPa. Analyzing other results of the tests it is visible that the properties of material are changing with increasing moisture content. They change from elastic to plastic bodies, and the obtained stress-strain curves are becoming much flattened. The illite clay strength generally decreases with increasing

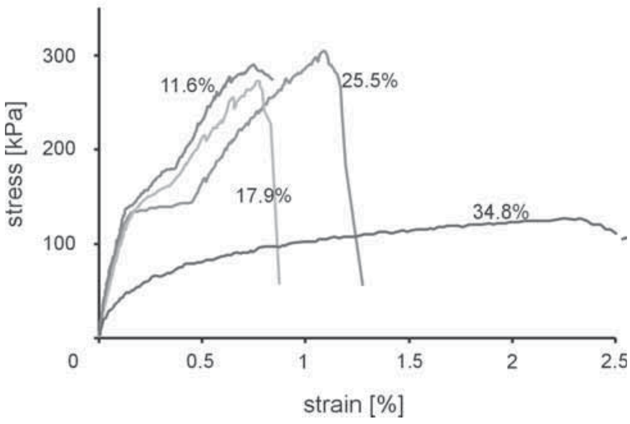

Fig. 3. Tensile test: stress-strain relation obtained for kaolin clay.

moisture content. The well-marked material strength is not visible on the given curves over 11.64%. But the error which can be made during the determination of material strength is small for the stress coordinate due to relatively flat character of the curves.

Otherwise, for the tensile tests, the material strength is well visible even for the samples of very high moisture content. In Fig. 3, the tensile stress-strain relation for kaolin clay of the given moisture content is presented.

One can notice more advantages of using tensile tests than compressive ones. The yield stress and plastic flow are well-marked on the stress-strain curve (*e.g.* for the sample of 25.5 % moisture content). So, one can acquire more precise data from tensile tests then compressive one but there are some problems to overcome. First of all, it is very difficult to mould good and long samples without any deformations for the considered materials in such a wide range of moisture contents. Of course simple rods are not the best sample shape for the use in tensile tests, but attempts of making the samples of more sophisticated shapes (with wider gripping part) have failed. Next very important problem appears with proper placing of samples in grips. The gripping force has to be very precise and delicate applied in order to avoid unique destruction of tested specimen. The last problem is the time. The experiment of 84 tensile tests takes approximately the same time or even more than performance of 221 compressive tests for three studied materials.

Fig. 4 presents comparison of tensile and compressive strengths for kaolin clay in dependence on moisture content. The character of these two relations is the same but the values of material strength for tensile stresses are generally lower than acquired from compressive stresses. In Fig. 4b, the yield stress observed in the kaolin samples during the tensile tests is also presented.

There are differences of material strength acquired from tensile and compressive tests. It is visible for kaolin clay that the strength values are lower in the tensile test and higher in the compressive one for the specimens in the overdried state. Such behaviour is common for brittle materials that are more sensitive for tensile stresses then compressive ones [6, 7, 10]. One can find that for some soils the tensile strength is lower than compressive one in the whole moisture content range [7]. It can also be caused by different ways of samples manufacturing. The samples used in the compressive tests were extruded while those used in the tensile tests were casted.

The theoretical dependence of tensile strength on moisture content for the ceramic mass is presented in Fig. 5. It is assumed that ceramic mass contains surface (Van der Waals) and ionic bonds as well [12]. The surface bonds are connected to the Van der Waals forces between material grains and ionic bonds are typical chemical bonds existing inside moist materials. The moisture content (Fig. 5) is described not in percentages but as a moisture content unit defined as the moisture where the maximal tensile strength exists (W_{op} - the optimal moisture content, in Fig. 5). Next multiplicity of that moisture content is lay off on the abscissa axis. More water added to the mass, behind the optimal moisture content, gives continuous fall of cohesion forces between grains of the material. With the continuous decrease of this force the material strength value decreases as well. Depending on the kind of existing bonds in material the strength decreases rapidly (dominating surface bonds) or slowly (dominating ionic bonds).

The surface bonds caused by the Van der Waals forces influence mainly material strength up to the optimal moisture content. These forces disappear (moisture content $3W_{op}$) due to growing a distance between grains [12]. For higher moisture contents the ionic bonds are responsible for material strength. They are connected with ions' changing capacity. The ions existing on the surface of the grains (They are usually kations) begin to hydrate and reach maximal forcing bonds near $3W_{op}$. For higher moisture contents the strength decreases since too much water appears in the material. Adding more water causes liquefaction of that ceramic mass.

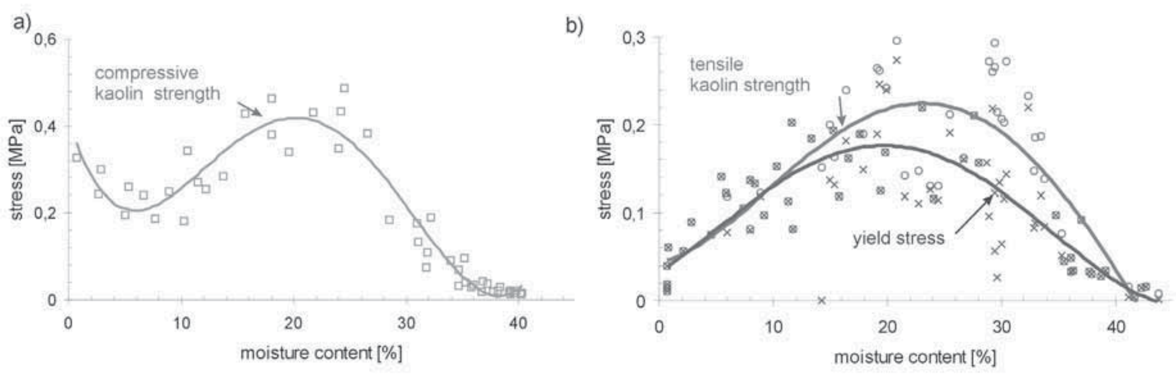

Fig. 4. Material strength of kaolin clay as a function of moisture content: a) compresive tests, b) tensile tests together with a plastic limit curve.

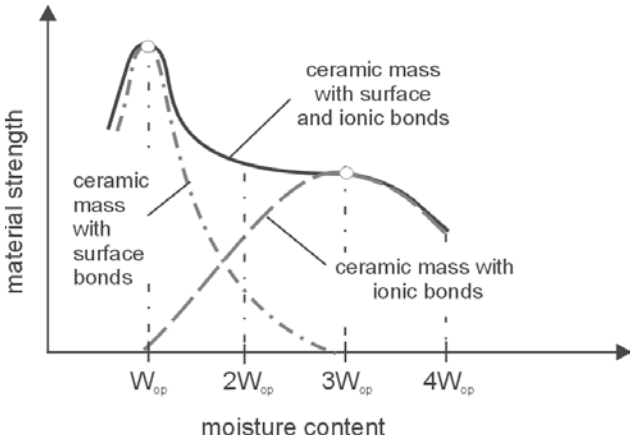

Fig. 5. Material strength of analyzed materials dependent on moisture content.

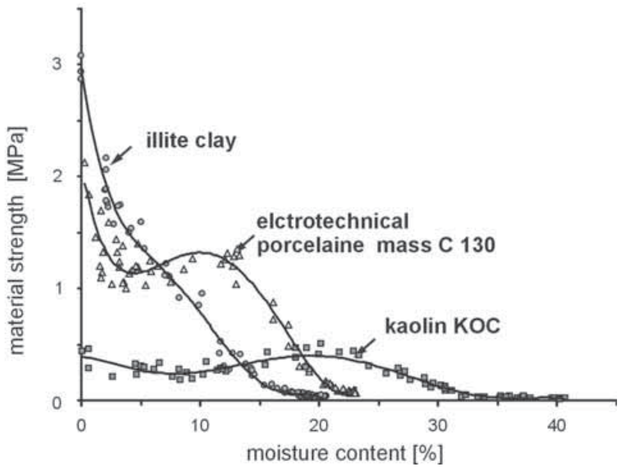

Fig. 6. Material strength of analyzed materials dependent on moisture content.

The results of all performed compressive tests are presented in Fig. 6. The material strength of clay is the highest of all analyzed materials in the overdried state but very quickly decreases with more water added. This is typical for materials where bonds connected with the Van der Waals forces between their grains dominate.

The electrotechnical porcelain C130 has higher material strength in the overdried state. Then the strength quickly decreases and stabilizes in interval from 5% to 15% of moisture content, and again falls wish increasing of the moisture content. The surface bonds between grains dominate over 5% of moisture content. Just like in illite clay they disappear very fast with growing distance between grains. Ionic bonds between grains start to raise and dominate in the material when some water is added. The material strength is decreasing when moisture content exceeds 15%.

Differently from previous materials maximal value of material strength of kaolin clay is not near the overdried state but at 22% of moisture content. The main reason of that phenomenon is that mainly ionic bonds occur in kaolin clay.

4. Conclusions

The strength of all studied materials evidently depends on moisture content. The highest values of compressive strength exist in the overdried state for illite clay and ceramic mass C130. The strength of illite clay decreases rapidly with increasing of moisture content because of existing surface bonds only. On the other hand the highest value of kaolin clay strength is noticed at 22%. That is mainly due to ionic bonds that are dominating in kaolin clay. This material is the least sensitive to moisture content changes of all analyzed materials. Ceramic mass C130 possess both surface and ionic bonds.

There are differences of material strength acquired from tensile and compressive tests. Strength of kaolin clay one low moisture content state is decreasing for tensile test and increasing for compressive test. Such behaviour is common for brittle materials, which are more sensitive to tensile stresses then compressive ones. The tensile strength is lower than compressive one in the whole moisture content range. It can be caused by different way of samples preparation. Samples used in compressive tests were extruded and ones used in tensile tests were casted.

The tensile tests provide more information about material (*e.g.* yield stress) but are more labour-consuming then compressive tests.

Acknowledgements

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