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Plasticity Changes of Moulding Sands with Chemical Binders Caused by Increasing the Hardening Degree

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Abstract

The results of investigations of plasticity of moulding sands with binders obtained by measuring deflection angles in the single point bend test in dependence on their hardening degree are presented in the hereby paper. Shaped samples made of moulding sands obtained in the technology with urea-furfuryl resin Furanol FR75A and in the technology with water glass, were subjected to various tests. Shaped samples were made on the quartz matrix of a medium grains size $d_l = 0{,}29\ mm$. Investigations were performed for the resin content being 1% and 2%, at a constant proportion of a hardener versus resin -- equal 60%. In the case of sands from the technology with water glass, investigations were performed for 3.5% of water glass versus sand matrix and 0.35% of Flodur. Plasticity tests were carried out with using the strength machine with a continuous recording of a sample deflection value. Measurements of deflection angles values in the bend test were performed on a series of simultaneously made samples at constant time intervals from the moment of their making. To determine the sand hardening degree the ultrasound technique was applied, according to the previously developed methodology [1]. Every time from the obtained results the characteristic of the growing stress as a function of deflection was prepared (σ). In addition, for the tested group of moulding sands, empirical relationships between the maximum deflection angle (α_{max}) in the bend test and the hardening degree were determined (S_x): $\alpha = f(S_x)$.

Keywords: Self-setting sands (SSS), Plastic properties, Hardening degree, Ultrasounds

1. Introduction

Moulding and core sands with chemical binders are - from the rheological point of view - visco-elastic media. These sands are relatively well described by the Kelvin – Voigt pattern, which idea is shown in figure 1. In this pattern, elastic as well as viscous properties occur near each other, a sort of, in parallel [2,3]. However, sands with binders, in which these binders - during the hardening process - are one by one passing from a liquid state via sol and gel states into a solid body, are rheologically unstable. As their hardening degree increases viscous properties are gradually disappearing to the benefit of elastic properties [4,5,6]. The effect of decaying of plasticity of moulding sands with binders is phenomenologically widely known. Much less known is the pathway of changing properties from viscous - at the beginning of sand bonding - up to elastic - in the final phase of the process.

In addition, from the practical point of view, it is important to know how many plastic features remained after the 'complete' hardening of the sand. The ability to small deformations of mould elements, without their breaking, is important when cores are placed in moulds. At too low ability to elastic-permanent deformations the cracking, or even breaking of cores can occur.

This problem is growing when the placement of cores is performed in a mechanical way by using various types of robots, manipulators, etc. A mould compliance for small deformations is also important when pattern is removed from it. When sand is too brittle breaking off of protruding elements, called projection cods, can even occur [7,8,9].

The attempt to determine the relationship between the hardening degree of moulding sand and its visco-elastic properties, constitutes the research subject. A hardening degree is controlled by ultrasound technique, while plastic properties by deflection angle values in dual-support bend test.

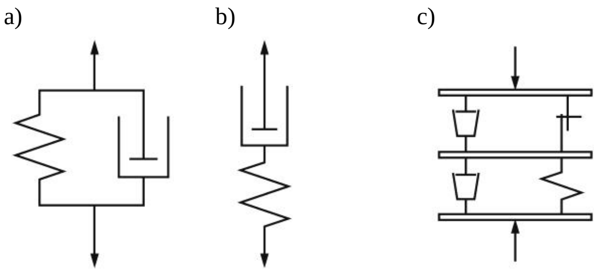

Fig. 1. Rheological patterns of moulding:
a/ Kelvin – Voigt pattern, b/ Maxwell pattern, c/ Complex pattern [2,3]

2. Own investigations

2.1. Aim and methodology of investigations

The determination of the relationship between the moulding sand hardening degree, controlled by the ultrasound technique (non-destructive) (S_x), and this sand plastic properties were the aim of investigations. This requires the determination of the moment in which the pattern is removed from the mould. Investigations related to determining plastic properties of moulding sands were performed on the research set-up for strength tests, of a maximal load equal 10 kN.

Fig. 2. Research set-up for strength tests R_g with the recorded pathway of the test

The research set-up is presented in Figure 2. The beam shaped sample, made of the tested sand, was placed on a support and the bending force - directed vertically down - was imposed on it. During the bending process, the sample deflection was recorded. The deflection angle values were - on this base - calculated in the bend tests. Tests were performed on the series of samples prepared of the given sand. Samples were subjected to breaking at certain times, which passed from the moment of their preparation. This allowed determining the influence of the sand hardening degree on plastic and plastic-elastic properties of the given sand.

The ultrasound technique was applied to assess the hardening degree (S_x) it means to recognise the advancement of the hardening process. Longitudinal wave velocity (C_L) was the tested parameter. The measurement was based on the placement of the sampler with the tested sample in between ultrasound heads and on recording the time of passing of the ultrasound wave through the sand sample - porous medium. This measurement was realised during the whole time of moulding sand bonding (from the moment of mixing all components). Ultrasound measurements were performed online on the research set-up shown in Figure 3. Results of measurements of wave velocities were recorded in short and declared time intervals, e.g. every 60 seconds. Ultrasound investigations were carried out at constant conditions of temperature and moisture content. Bend tests and ultrasound investigations were performed simultaneously at the same time. Both research set-ups were in the same room. The hardening processes in both cases were carried out under the same conditions and sands were bonding at similar rates.

Fig. 3. Research set-up for ultrasound tests of pathways of bonding moulding sands with chemical binders

2.2. Kinds of performed investigations

Shape samples were made of the moulding sand on the quartz matrix BK55 of the Sibelco Company Poland. Average size of matrix grain equaled $d_l = 0{,}29\ mm$. Urea-furfuryl resin Furanol FR75A of the PrecOdlew Company was used in investigations. A hardener intended for this type of resins is PU6 hardener (of the PrecOdlew Company) containing paratoulenesulphonic acid. During tests the constant resin amount 1% and 2%, in relation to the sand matrix amount was maintained. The ratio of the hardener to resin, equaled 60%, was also constant. In case of moulding sands of the technology with water glass, investigations were performed for 3.5% of water glass and 0.35% of Flodur, with regard to the sand matrix amount.

Investigations were performed at a constant ambient temperature and relative moisture content of the air. For 1% of resin content - $T = 23°C$; $W = 49\%$. For 2% of resin content - $T = 25°C$; $W = 57\%$. While for sand of the technology with water glass - $T = 21{,}5°C$; $W = 42\%$.

Bend tests were realised on samples of dimensions: 172x22.36x13 mm (length, width, height). They were performed in the sampler (Fig. 4), specially designed for such tests. Measurements of plastic properties of moulding sands, described by the deflection angle value, were performed at constant time intervals, from the moment of mixing all components. Times of making measurements of deflection angles in the bend test are shown in Table 1.

Fig. 4. Sampler for making shaped elements intended for measuring the deflection angle in the bend test

Table 1.
Time intervals of measuring deflection angles in bend tests for the selected group of SSS sands

Moulding sand kind	**Time from the moment of mixing the moulding sand components**								
SSS with organic binder containing 1% of resin	40 min	50 min	60 min	80 min	100 min	120 min	150 min	180 min	24h
SSS with organic binder containing 2% of resin	from 20 min to 60 min (every 5 minutes)			80 min	100 min	from 120 to 420 min (every 30 minutes)		from 17h to 21h (every 30 minutes)	24h
SSS with inorganic binder containing 3.5% of water glass	from 60 min to 120 min (every 5 minutes)						150 min	210 min	24h

Shaped samples were taken - at the determined time intervals - from the sampler one by one, in order to limit the vapour exchange rate from the sand to the surroundings. Next, the sampler was covered and tests were performed on the research set-up for strength tests.

In contrast to previous studies [10,11] tests were performed on samples different than the standard ones (for testing Rg of moulding sands). Standard shape elements are of square cross-sections: 22.36x22.36 mm. It was noticed that deflection angles in the bend test performed on standard shaped samples were characterised by very small changes during the bonding period of moulding sands.

It can be proved, by means of strength calculations, that in order to obtain the same deflection in the standard sample (of the cross-section 22.36 and height 22.36 mm) as in the sample of the same cross-section and height equaled 13 mm, nearly three times higher maximal stresses should be generated. This results from strength indicators of beam bending, where height ‘h’ occurs in the square ($22.36^2/13.0^2 = 2.958$). By decreasing the sample height the effect of better sensitivity of bend tests was achieved. This allowed recording pathways of bending in a wider range of measured values. It should be added, that moulding sands with chemical binders are rheologically unstable media. In the initial phase of bonding, they are visco-elastic while as the ‘hardening’ time goes by they become elastic-viscous to become purely elastic at the end

The ultrasound technique was applied in order to relate the plastic properties of investigated moulding sands to their hardening degree. The so-called moulding sand hardening degree was determined (S_x). This degree is used for assessing the advancement of the hardening process, since it informs at which hardening phase is the tested sand in the very moment. The hardening degree is defined by formula (1), which is based on a dimensionless ultrasound wave velocity [12]:

$$S_x = \frac{C_{L(x)} - C_{L(0)}}{C_{L(\max)} - C_{L(0)}} \qquad (1)$$

where:
S_x – hardening degree of moulding sand,
$C_{L(x)}$ – wave velocity in the sample, determined in the given moment (t_x),
$C_{L(0)}$ – wave velocity in the sample at the beginning (t_0),
$C_{L(\max)}$ – wave velocity in the sample after its complete hardening.

During the measurement, samples of the tested moulding sand were in the closed sampler placed between ultrasound heads (Fig. 3). Measurement conditions matched conditions that were in the middle part of the mould, being at some distance from its open surface. The ultrasound wave velocity - from the moment of mixing all components - was recorded at constant time intervals. These intervals were the same as the ones, after which plastic properties of moulding sands were tested on the research set-up for strength investigations.

Figure 5 presents the example of the pathway of the hardening degree changes S_x of self-setting moulding sand with urea-furfuryl resin Furanol (FR75A). This course was obtained by measuring the ultrasound wave velocity.

The sampler was placed in a tight temperature chamber, in which the temperature was identical as the matrix temperature of the tested moulding sand.

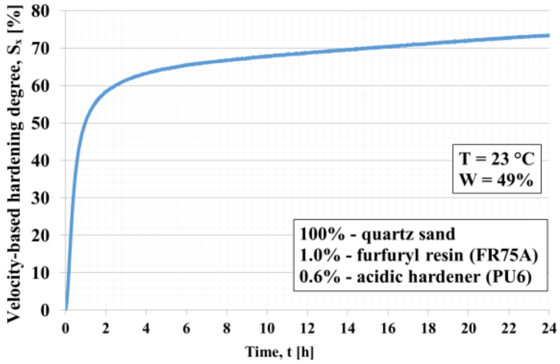

Fig. 5. Changes of the hardening degree S_x of moulding sand with organic binder subjected to investigations of the deflection angle dependence on the hardening degree S_x

On the basis of the course of the hardening degree changes, in the time unit, it is possible to determine such parameters as: the time of initial and of complete hardening, as well as the advancement degree of the hardening process. It was found, in the case of the presented course (Fig. 5), that the pre-hardening time ($S_x = 70\%$) equaled approximately 14h, while the time at which the mould was ready to be poured with liquid alloy was above 24 h. (S_x must be equal at least 90%).

Analyses of the obtained results allow expecting that it is possible to use the tested sand in a foundry practice when stages of its preparation, moulding and bonding are performed at a temperature near 23°C. When the obtained hardening degree reaches 70%, the pattern can be safely removed from the mould, without any risk of this mould distraction.

2.3. Investigations of the moulding sands plasticity by means of measuring deflection angles in bend tests

Typical courses of bending recorded on the strength machine are shown in Figure 6. Results are listed in the system: deflection - stresses (σ = f(α). Courses for three levels of hardening are shown (Fig. 6). It can be noticed, that as the hardening degree increases the deflection decreases. Stress values, at which the sample is broken, are increasing.

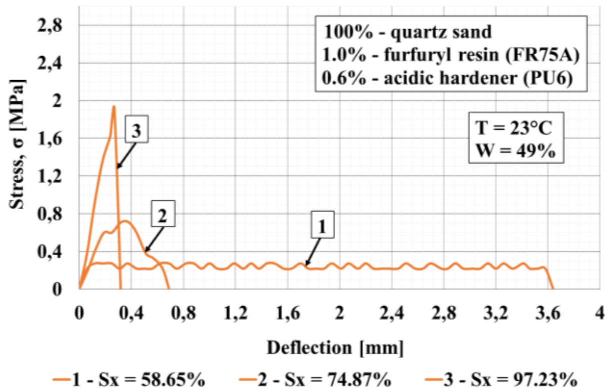

Fig. 6. Relationship between deflection and stress in the bend test (sand with 1% of resin), for three values of the hardening degree S_x

As the bonding is increasing moulding sand with a chemical binder loses its plastic properties (the ability for deformations) on account of elastic properties and strength. In approximation, the period of elastic deformations corresponds to the part of the diagram (Fig. 6) in which stresses are increasing proportionally to increasing deflection.

Empirical dependencies of plastic properties of sands with organic binders on the hardening degree are shown in Figs. 6 - 9. These relationships were determined for moulding sands containing 1% (Figs. 6 and 7) as well as 2% of resin (Figs. 8 and 9). The hardener proportion to resin was constant and equal 60%.

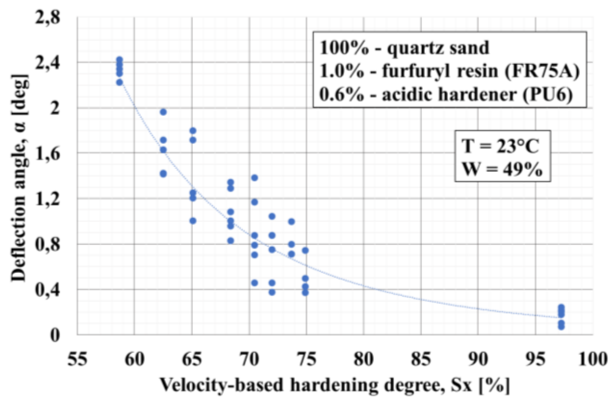

Fig. 7. Dependence of the deflection angle (α) on the sand hardening degree S_x, of the moulding sand with an organic binder containing 1% of resin

Analysing the relationship between the deflection angle and hardening degree $\alpha = f(S_x)$ (Figs. 7 and 9) of the moulding sand with an organic binder, it was found that as the hardening degree increases the deflection angle decreases. Regardless of the percentage resin fraction (1% or 2%), when the hardening degree increases the elastic properties of the sand are decreasing. In the case of the sand containing 1% of resin $S_x = 58\%$,, deflection angle values are from 2.2° to 2.4°, while for the sand containing 2% of resin - from 4.6° to 4.8° $S_x = 59\%$. Also final values of deflection angles, at the same hardening degrees - $S_x = 97\%$, are significantly different. For the sand containing 1% of resin - results from 0.07° to 0.24° are obtained, while for the sand containing 2% of resin - from 0.42° to 0.49°.

Moulding sands with higher amounts of binders are generally characterised by better elastic properties. Probably the increased content of binders causes higher elasticity of bridges joining individual grains in the matrix. This also leads to increasing elastic properties of sands containing more resin, even after the complete hardening of these sands (Figs. 6 - 9).

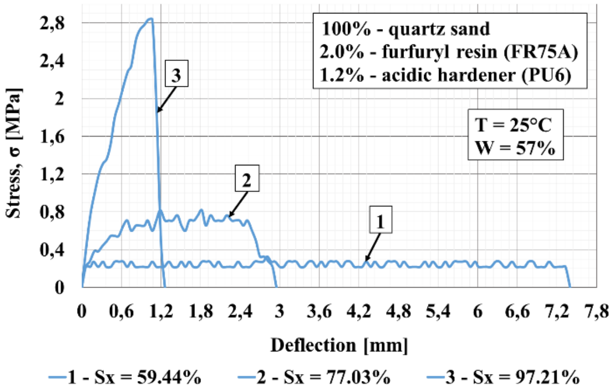

Fig. 8. Relationship between the deflection and stress in the bend test, for three values of the hardening degree S_x (sands containing 2% of resin)

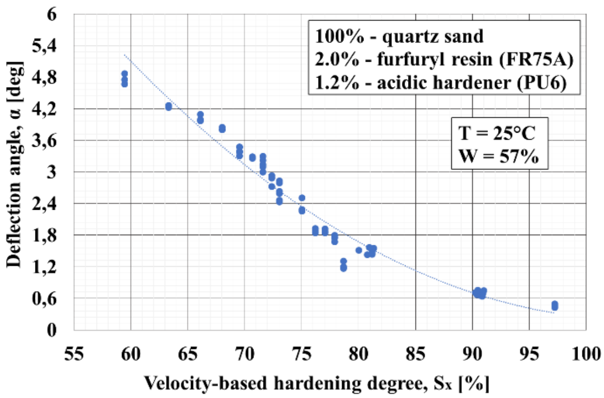

Fig. 9. Dependence of the deflection angle in the bend test on the hardening degree S_x for moulding sand with an organic binder containing 2% of resin

Examples of the relationship between plastic properties of self-setting moulding sands with inorganic binders and the hardening degree of sand containing 3.5% of water glass are presented in Fig. 10.

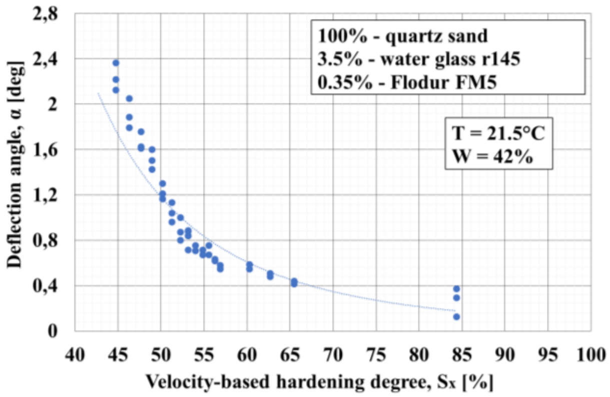

Fig. 10. Dependence of the deflection angle of the sample on the hardening degree S_x, for moulding sand with an inorganic binder containing 3.5% of water glass

On the bases of data illustrated in figure 10 S_x, it was established that the increase of the hardening degree led to decreasing the deflection angle value. As the result of the performed analyses, it was found that moulding sand from the technology with water glass had the lowest plastic properties, out of all tested sands (Fig. 11).

Analysing bending courses of tested sands (Figures 6 and 8), it was noticed, that in every case when the hardening degree was increasing S_x, moulding sand strength was also increasing. This is related to changes in the state of the system which constitutes the matrix together with the binder: from visco-elastic, via elastic- permanent (with decaying elasticity) finally up to nonlinearly-elastic.

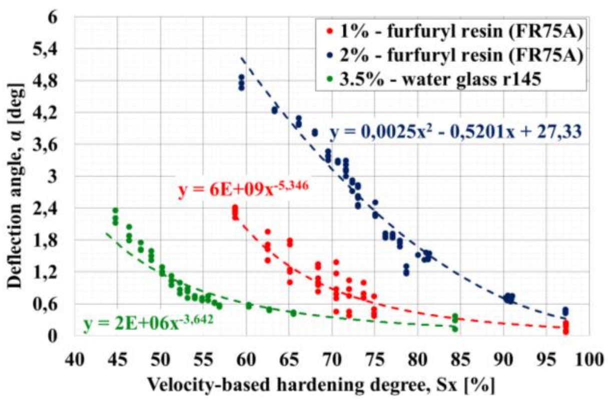

Fig. 11. Comparison of the dependence of the sample deflection angle on the hardening degree S_x, of moulding sands with organic binders containing 1% and 2% of resin and for sand with an inorganic binder containing 3.5% of water glass

An increase in strength properties is strongly related to the plastic properties of sands. Hardening processes of all tested sands are accompanied by strength increases and plastic properties decreases (Figs. 6 and 8). In addition, in the case of sands with organic binders, the increased resin content leads to increased strength properties (Fig. 9).

The shaped sample made of the moulding sand with an organic binder (resin content - 1%) is shown in figure 12 after the measurement of the deflection angle in the bend test. The sand hardening degree was $S_x = 58\%$.

Fig. 12. Shaped sample of the sand with organic binder, after the measurement of the deflection angle in the bend test (for the hardening degree $S_x = 58\%$)

3. Summary

The conclusions of the performed analyses are written below.

- It is possible to find the relationship between the elastic properties of self-setting moulding sands and their hardening degree.
- When the hardening degree increases plastic properties of SSS are also decreasing.
- An increase in the resin content in sand leads to increasing plastic properties during the whole hardening period.
- Increasing moulding sand strength caused by growing hardening causes decreasing in its plastic properties.
- Sands with water glass are characterised by a lower ability for deformations (in bend tests) than sands with organic binders.

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