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Kinetics of the Binding Process of Furan Moulding Sands, Under Conditions of Forced Air Flow, Monitored by the Ultrasonic Technique

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Abstract

The paper presents the results of research on the kinetics of the binding process of self-hardening moulding sands with an organic binder under conditions of forced air flow at various pressure values. Three moulding sands made using urea-furfuryl resin Furanol FR75A technology were studied. The moulding sands were prepared on a base of quartz sand with an average grain size of $d_L = 0.25, 0.29$ and 0.37 mm, with permeability values of $306, 391$ and $476\ m^2/10^8 Pa \cdot s$ (for $\rho_0 = 1.60, 1.60$ and $1.61\ g/cm^3$, respectively). The research was conducted for a resin content of 1% with a constant proportion of hardener to resin, which was equal to 50%. Samples of the tested moulding sands were blown with air at pressures of 0.1, 0.2, 0.4, 0.6, 0.8, and 1.0 bar. The kinetics of the hardening process was monitored using ultrasound technology, according to a previously developed methodology [1]. The research was carried out on an ultrasound testing station equipped with a temperature chamber and an airflow reducer. The tests were conducted at a temperature of 20°C, and of the air flow pressure on the changes in ultrasonic wave velocity in the hardening mouldins sand as a function of time, the kinetics of the hardening process, and the degree of moulding sand hardening were determined. Additionally, the influence of the moulding sand permeability on the course of the hardening process at a constant air flow pressure was determined.

Keywords: Self-hardening moulding sands, Air flow, Permeability, Degree of hardening, Ultrasound

1. Introduction

Moulding sands with furfuryl resins belong to the most often used kinds of sand with non-bake type of binders [1]. Their general usage is caused by several good points. These sands are characterised by a wide possibility of regulating their service life, good knock out property and high strength. Castings made in moulds prepared from sands with furfuryl resins are characterized by a high dimensional accuracy. However, as every technology, this one has also certain faults. Essential problems constitute: an influence of temperature on the sand service life, high costs of resins as well as the storage of spent sands and after reclamation dusts [2,3]. The fact that these sands have a long setting time is also important in the technological process. The setting process of sands with furfuryl resin is not only physical but also chemical [4]. During this process water and volatile binder components are evaporating from a sand and binder bridges are forming between matrix grains [5,6]. As a result of the resin polymerization, water – as a side product - is emitted [7]:

$$R\text{-}CH_2OH + H \rightarrow R\text{-}CH_2 + H_2O \quad (1)$$

A difficult exchange of vapours from a sand into surroundings in the central parts of a mould, being directly at the model, causes significant prolongations of the setting time [8]. In order to achieve the technological strength, water and volatile components of a binder must be removed from a sand. In a standard binding process it takes approximately 24h [9].

2. Own investigations

2.1. Aim and methodology of investigations

The determination of the influence of the forced air flow on the hardening process of moulding sands with organic binders was the aim of the performed research. The influence of the pressure value of the air introduced into the sand and the sand permeability were determined. Kinetics of the sand setting process was tested on the research station for ultrasound technique [10]. Tests were realized in a chamber, of a possibility to stabilize the temperature, which was extended by the set up for dosing the compressed air to the sample during the moulding sand setting (Fig. 1).

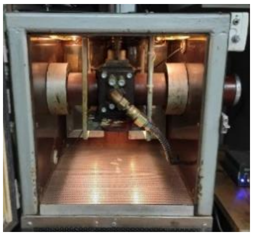
a)  b) 

Fig. 1. Research station for testing, by means of the ultrasound method, the kinetics of setting of moulding sands with binders, a) testing chamber; b) system of controlling the pressure and the compressed air flow [10]

The investigation consisted in placement of the sampler with a sand in the testing chamber and measuring velocity changes of the wave propagation in the hardening sand. After the sampler placement in the chamber and starting the ultrasound measurements the air from the control system was flown through the sample. Sand binding was performed under the condition of forced air flow at a temperature of surroundings (without heating). The measurement was performed during the whole period of the sand binding, from the moment of the sampler placement in the measuring system up to the complete binding of the sand. Results were recorded on-line every 10 seconds.

Investigations were performed at maintaining constant outside conditions, at the same temperature. During the measurements sand samples were in a closed sampler. This corresponds to conditions which are in the central parts of the mould, in layers being at the model. In each test the sand sample was blown by the air at a constant pressure during the whole hardening period.

In order to obtain a uniform air flow in the whole shaped sample, a foam filter was placed in the sampler, directly after the air intake. (Fig. 2).

Fig. 2. The sampler used in testing the sand binding and the hardened shaped sample after its knocking out from the sampler

A gas flow in a porous medium is determined by the porosity of this medium, which measure is its permeability. In order to determine the permeability of tested sands, each time after knocking out the hardened shaped element from the sampler its density was tested. On the bases of the obtained density results, standard cylindrical specimens (of the same density as in a sampler) were prepared for every tested sand. Then the permeability of the hardened sands was determined.

2.2. Types of the performed investigations

The kinetics of the binding process of furan sands under conditions of forced air flow was tested for sands prepared on the base of quartz sand Sibelco Poland of an average grain size: $d_L = 0.25, 0.29$ and 0.37 mm (Table 1)

Table 1.
Composition of self-hardening moulding sands with organic binders, subjected to tests

Sand marking	Base	d_L [mm]	Binder	Hardener
SMS 1	100% - quartz sand	0.25	1%	0.5%
SMS 2		0.29		
SMS 3		0.37		

As a binder was applied urea-furfuryl resin Furanol FR75A of the PrecOdlew Company with a hardener PU6, which is a mixture of two acids: paratoulenosulphonic and sulphuric (5%). The constant amount of resin was used – 1.0 % in relations to the amount of sand base and the constant relation of a hardener to resin (H/R = 50%). Research was performed at a temperature: $T = 20°C$.

The air flow in each test, was at a constant pressure from the range: 0.1 to 1.0 bar. The measured time of the sand binding was equal 1 hour (Table 2).

Due to the fact, that a gas was used as a factor supporting hardening of sands, the determination of the sands permeability at the same compaction as obtained in the sampler, was aimed. A permeability depends on the base grains size, on binder amount and sand density. The permeability of sand, compacted by means of a servo-motor in a sampler, was determined in two stages. At first the sand density was gravimetrically determined for samples knocked out – after hardening – from the sampler. Then, from the same sand cylindrical specimens ø50x50mm of the same density were prepared. The permeability was measured in a standard way on the prepared cylindrical shaped elements in a hardened state. The obtained results are shown in Table 3.

Table 2.
Conditions of testing the kinetics of sand binding at a forced air flow

Sand marking	T [°C]	Flow	p [bar]	t [h]
SMS 1	20	Air	0.1 0.2	1
SMS 2			0.4 0.6	
SMS 3			0.8 1.0	

Table 3
Permeability of sands in the sampler for ultrasound tests under conditions of forced air flow

Sand marking	ρ_0 from a sampler [g/cm^3]	ρ_0 shaped element [g/cm^3]	P^u [$m^2/10^8$ Pa · s]
SMS 1	1.60	1.60	306
SMS 2	1.60	1.60	391
SMS 3	1.61	1.61	476

The kinetics of hardening processes was determined by the ultrasound method [10]. On the base of the wave velocity measurement the so-called: degree of sand hardening was determined (S_x). The degree of sand hardening is defined by equation (1), based on the dimensionless velocity of the ultrasound wave [3]:

$$S_x = \frac{C_{L(x)} - C_{L(0)}}{C_{L(\max)} - C_{L(0)}} \quad (2)$$

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

During tests the sample was in the closed sampler placed between ultrasound heads (Fig. 1.a). The wave velocity value was recorded every 10 seconds.

Figure 3 presents the example of the hardening course of SMS with resin (Furanol FR75A) in 24h. The pathway was determined on the base of the ultrasound wave velocity measurement in binding sand. Pathways in all measurements of the sand binding, under conditions of forced air flow, were determined in a similar way.

In the case of pathway presented in figure 3 it was found, that the time of a preliminary hardening of the tested sand ($S_x = 60 - 70\%$) equals nearly 4h. After this time, it is possible to dismantle the mould and take out the model. After 24h the mould is ready to be poured with liquid alloy (S_x ~ 90%).

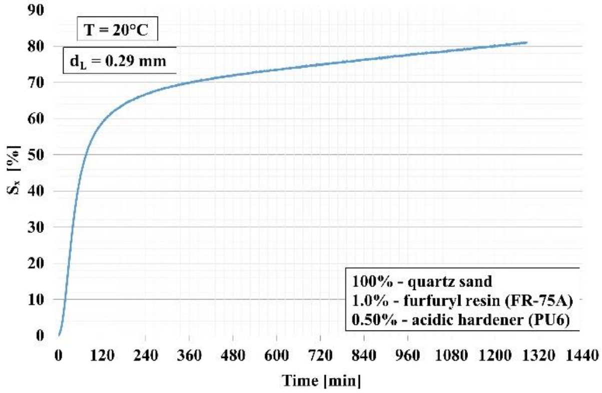


Fig. 3. Hardening pathway (S_x) SMS of furan sand in 24h

2.3. Binding of furan sand under conditions of forced air flow

Pathways of binding three different sands of a permeability values: 306, 391 and 476 $m^2/10^8$ Pa·s under conditions of forced air flow, in dependence of the pressure value, are presented in figures 4 -6.

The binding process of SMS with organic binder can be divided into two stages. The first one has very intensive increases of the hardening degree in the time unit, because amounts of reaction substrates are very high. In the second stage increases are less intensive and a slowing down of the sand hardening is observed. In the ultrasound technique of investigating the binding kinetics the changes of instantaneous velocity of the wave propagating the binding sand are recorded. The recorded pathways of the wave velocity changes in the binding sand, through which the air stream is passing at the defined pressure in its intake, are presented in Fig. 4. The sand was characterized by a permeability P^u = 476 $m^2/10^8$ Pa·s. A similar character of pathways was recorded for the remaining sands of a slightly lower permeability.

The increase of the air flow pressure leads in all sands to the increase of the wave velocity and sands hardness degree in the first stage of the binding process. At this stage, water and volatile components of binders are removed from a sand. Forced air flow facilitates exchanges of vapours from sands to surroundings, by means of physical influences. From a chemical point of view, formation of bridges joining base grains occurs without a blow-through, as in the standard process. Removal of water and volatile binder components, which are slowing the binder transfer from a sol state into gel state leads to a successive elimination of the factor slowing down the binding process. When the air flow pressure increases volatile components are faster removed from a sand. This causes increases of a wave velocity in the first stage of the process.

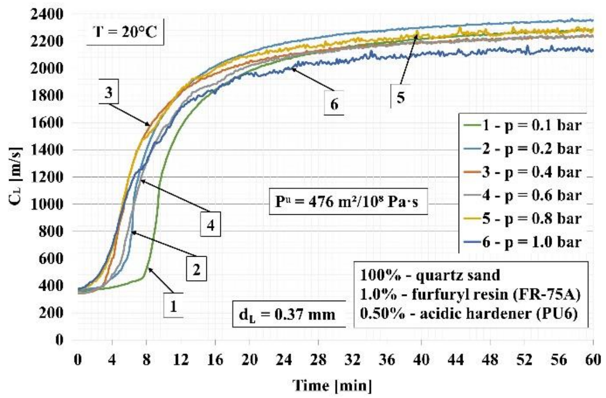


Fig. 4. Pathways of changes C_L in the binding sand of a permeability P^u = 476 $m^2/10^8$ Pa·s. Blow-through at p = 0.1 – 1.0 bar

In the second stage of the binding process, when the contents of reaction substrates is lower and lower and a binder joining grains is entering into a gel state (elastic), the velocity increase is more intensive at increasing pressure of the air flow. A pressure increase leads to faster moving of the air stream in the sampler.

In order to determine velocities of changes occurring along with a hardening time of SMS with furan resin under conditions of forced air flow, the kinetics of the hardening process was determined. For the sand SMS 3 the results are shown in Fig. 5. It can be noticed that along with the pressure increase the time of obtaining the maximum derivative (of a process velocity) is shortened.

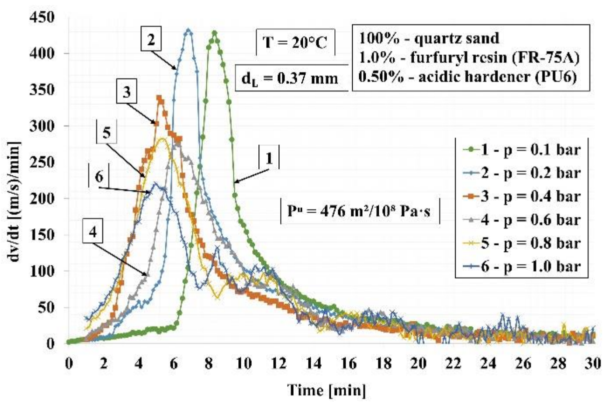


Fig. 5. Influence of the pressure of air stream flowing through sand SMS 3 on kinetics of its hardening (P^u = 476 $m^2/10^8$ Pa·s)

Similar pathways were obtained for the remaining sands: SMS 1 and SMS 2. The lower sand permeability the slower changes of a binding velocity.

For the sand of permeability of 476 $m^2/10^8$ Pa·s (Fig. 5) the most intensive velocity increase of the hardening process was observed at the flow-through pressure p = 0.2 bar. It was approximately 450 (m/s)/min (Fig. 4). The obtained final velocity, was the highest and equal nearly 2400 m/s.

During the analysis of the obtained results of the influence of the air flow pressure on the kinetics of the hardening process of the sand having a permeability of 476 $m^2/10^8$ Pa·s (Fig. 5), it was found that in case of this sand this influence is the highest. Higher air pressure and high permeability lead to a significant shortening of the time needed for removal of water and volatile components of a binder (Fig. 5).

The influence of the forced air flow on changes in the hardening degree during the sand SMS 3 binding process is shown in figure 6. Similar pathways were recorded for sand SMS 1 and SMS 2.

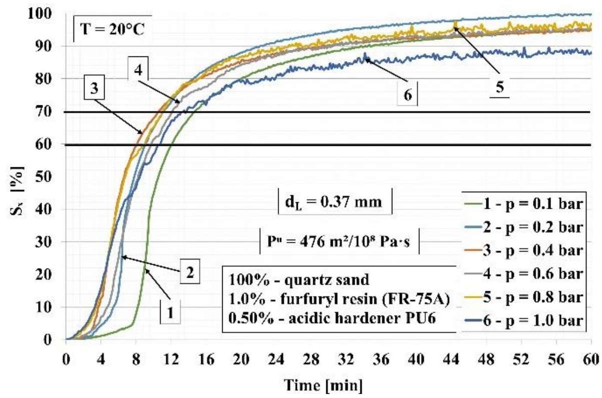


Fig. 6. Influence of the air stream pressure on the hardening of sand of a permeability equal: P^u = 476 $m^2/10^8$ Pa·s

On the bases of the pathways of changes the hardening degree of furan sand under conditions of forced air flow (Fig. 6) it was found, that facilitation of vapours exchanging from sand into surroundings leads to a significant shortening of the hardening time (from 24h to approximately 1h).

In a majority of tests, already after 60 minutes of a constant blowing, the obtained hardening degree: S_x ~ 90%, which corresponds to the hardening level in the mould ready to be poured with liquid metal.

2.4. Influence of a permeability on sand binding under conditions of forced air flow

Gas flow velocity through a porous matter is determined by the pressure gradient at the inlet and outlet as well as by a porosity degree (which measure constitutes a permeability value). The analysis aimed at determining the permeability influence on the sand binding under conditions of forced air flow was performed for the tested sands (Table 1-3). In figure 7 the results of ultrasound investigations at the air flow forced by pressure: p = 0.2 bar, is presented. A higher permeability value allows a faster removal of water and volatile components of binder, which generally accelerates a sand hardening.

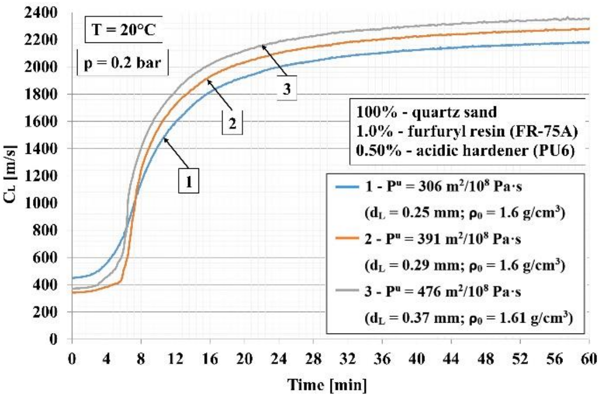


Fig. 7. Pathways of the hardening of sands of a permeability: P^u = 306; 391 and 476 $m^2/10^8$ Pa·s under conditions of forced air flow, for p = 0.2 bar

The results of the influence of sand permeability values on the kinetics of the hardening process determined by the ultrasound technique, under conditions of forced air flow, for p = 0.2 bar, are presented in figure 8. An increase of a sand permeability leads to increasing instantaneous velocities of sand binding. The faster removal of a factor slowing down sand hardening (water and volatile binder components), the higher reaction intensity in the first period of binding.

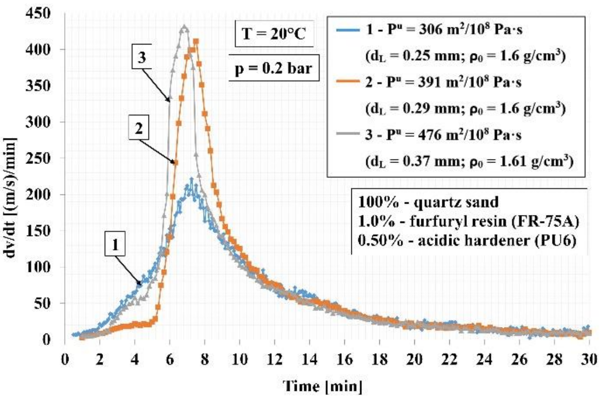


Fig. 8. Kinetics of binding process of furan sands of various permeability, under conditions of forced air flow at p = 0.2 bar

The influence of sand permeability on the hardening degree changes under conditions of forced air flow, at p = 0.2 bar, is shown in figure9. The previously described effect, that sand permeability increasing causes the hardening velocity increase, was confirmed. In addition, the final value of the hardening degree for the sand of a permeability of 476 $m^2/10^8$ Pa·s is the highest out of the obtained values and equals: $S_x = 99\%$.

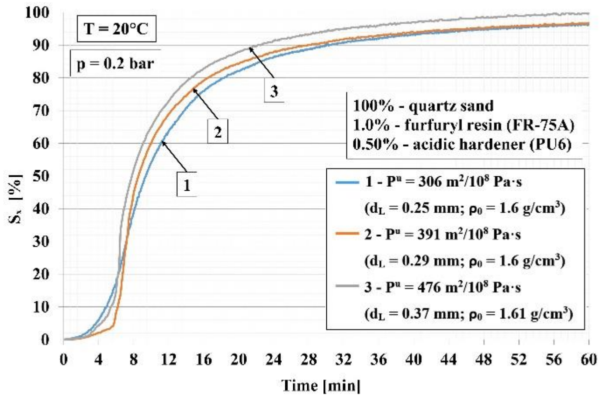


Fig. 9. Changes of the hardening degree of furan sands under conditions of forced air flow, at p = 0.2 bar

Furan sand hardened in approximately 60% in a casting mould allows to perform the model removal. In the traditional technology such state is obtained after 1 – 4h. In the technology with a forced air flow this time is much shorter. Results concerning preliminary hardening times of sands of various, but technologically real, permeability are shown in Fig 10. For the tested range of various permeability, its influence on the preliminary hardening time is of a linear character. Time of the preliminary hardening oscillates around 10 minutes. Results concern investigations under the previously described conditions – sand binding in a small sampler.

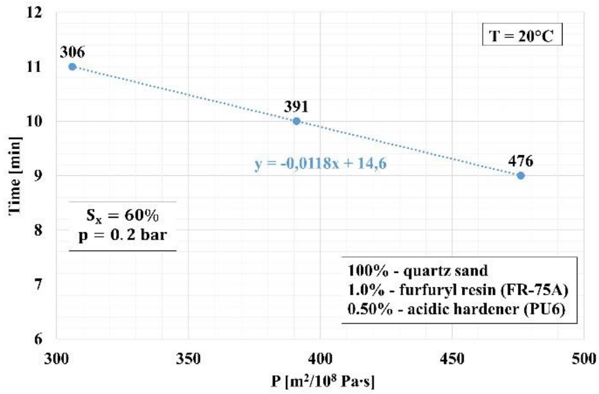


Fig. 10. Influence of the sand permeability on the preliminary hardening time, under conditions of forced air flow, at the air stream pressure: p = 0.2 bar

3. Discussion of the obtained results

It was found, on the basis of the performed investigations, that the forced air flow through SMS, with a furan binder, significantly accelerates the hardening process. The removal of water and volatile binder components from a sand leads to its faster transition from the visco-elastic state, via elastic-plastic with a disappearing plasticity to nonlinear-elastic state. Such information provides increasing velocity of the ultrasound wave in a binding sand. (Figs 4, 7). Shortening of the binding time of furan sand is significant, from 24h to only 1h (Figs 6, 9).

It was found during the tests, that the favourable binding course is obtained at relatively low pressure of pressed air, p = 0.2 bar (Figs 4, 7). The character of wave velocity was stable within the whole period of binding (Fig. 7).

In order to present the scale of changing the velocity of the hardening process of furan sands under conditions of forced air flow, the obtained results were compared with the classic binding process of 24h, without air blowing (Figs 11-12).

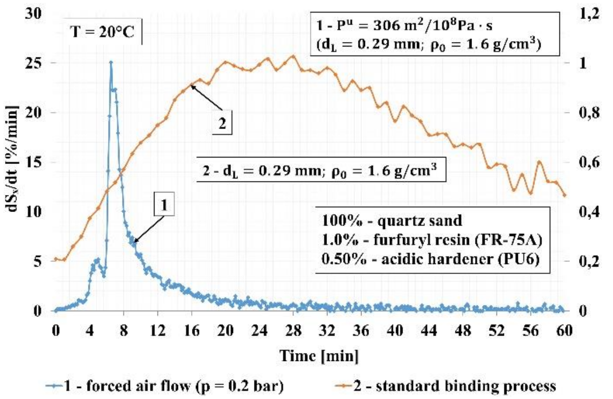


Fig. 11. Comparison of the kinetics of the sand hardening process, under conditions of forced air flow, with the classic sand binding process

After the removal of water and volatile components of a binder, very rapid increase of the reaction velocity is observed (approximately 25 %/min). In the standard hardening process, on account of the presence of water and binder volatile components, the binding reaction course is gentle (approximately 1 %/min).

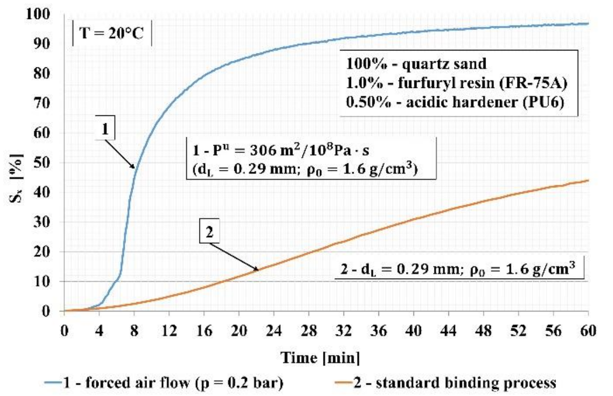


Fig. 12. Comparison of the changes of the hardening degree (S_X) of sand under conditions of forced air flow, with the standard process of sand binding

The comparison presented in figure 12 indicates that the water content in a sand has a very high influence on the course of sand hardening.

4. Conclusions

The following conclusions are drown after the analysis of the obtained results:

- Forcing the air flow through SMS with furan resin makes possible, by means of the physical influence, to remove water and volatile components of a binder which are slowing down the complex physical-chemical binding process.
- Favourable courses of the sand binding process under conditions of forced air flow, were obtained for pressure: p = 0.2 bar,
- The sand blown through at a constant low pressure (p = 0.2 bar), had probably the highest strength properties out of all tested sands.
- The higher sand permeability value the faster its hardening process under conditions of forced air flow.
- Removal of water and volatile components of a binder from the sand, by means of the forced air flow allows for a multiple shortening of the binding time. In the tested conditions the shortening from ~ 24h to ~1h was achieved.

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